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Using Sr[Mg3SiN4]Eu2+ phosphor for enhancing color uniformity and luminous efficacy of the 7000 K IPP-WLEDs

Van-Duc Phan[1], Duy-Hung Ha[2], Minh Tran[3], Tran Thanh Trang[4]
[1]Center of Excellence for Automation and Precision Mechanical Engineering, Nguyen Tat Thanh University, Vietnam
[2]Wireless Communications Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[3]Optoelectronics Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Vietnam
[4]National Key Laboratory of Digital Control and System Engineering, Vietnam

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ABSTRACT

In this paper, we built the simulation model of the 7000 K in-cup phosphor packaging white LEDs (IPP-WLEDs) by using the Light Tools software. After that, the effect of the Sr[Mg3SiN4]Eu2+ phosphor particle's size on the lighting performance in term of CCT Deviation (D-CCT), Color Rendering Index (CRI), Color Quality Scale (CQS), and Lumen Output (LO) is investigated. Moreover, the scattering processes in the phosphor layers of the 7000 K IPP_WLEDs is derived using Mat Lab software. From the research results, we can state that the phosphor size significantly affects the lighting performance of the 7000K IPP_WLEDs.

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Corresponding Author:

Duy-Hung Ha,
Wireless Communications Research Group,
Faculty of Electrical and Electronics Engineering,
Ton Duc Thang University, Ho Chi Minh City, Vietnam.
Email: haduyhung@tdtu.edu.vn

1. INTRODUCTION

Light-emitting diodes (LEDs) using semiconductors offer an alternative method of illumination. The operation of LEDs is based on spontaneous light emission in semiconductors, which is due to the radiative recombination of excess electrons and holes [1-6] that are produced by the injection of current with small energy losses. As a result, compared with conventional lamps, LED-based light sources have a superior lifetime, efficiency, and reliability, which promise significant reductions in power consumption and pollution from fossil fuel power plants [1–6]. LEDs is a solid-state light source which emits white light based on a blue die covered by the yellow or green-red phosphor. Such a light source has been intensively applied to general lighting and replaced most light sources in general lighting and even in special lighting (automobiles, transportation, communication, imaging, agriculture, and medicine) owing to its many advantages [3-5], sources shortly [6-8].

Although there are lots of issues needed to be addressed in white LEDs, such as chip processing, light extraction efficiency, heat sink structures, resin materials, reliability, life test, etc., this paper focuses on phosphors materials and their applications in white LED packaging. Phosphor coating is the most critical fluid flow problem in LED packaging since the coating process determines the phosphor thickness, location, distribution, and morphology in LED packaging. Moreover, changing the phosphor location will affect the LEE and CCT of LEDs. Phosphor thickness and concentration are the second consideration in LEDs because the luminous flux and color of LEDs are adjusted mainly through changing the thickness and concentration. Thickness and concentration can be varied in manufacturing and will, therefore, affect the optical consistency of LEDs [9-15].

As a novel class of inorganic phosphors, oxynitride and nitride luminescent materials have received considerable attention because of their potential applications in solid-state lightings and displays. In this paper, we built the simulation model of the 7000 K in-cup phosphor packaging white LEDs (IPP-WLEDs) by using the Light Tools software. After that, the effect of the Sr[Mg3SiN4]Eu2+ phosphor particle's size on the lighting performance in term of CCT Deviation (D-CCT), Color Rendering Index (CRI), Color Quality Scale (CQS), and Lumen Output (LO) is analyzed and investigated. Also, the scattering processes in the phosphor layers of the 7000 K IPP-WLEDs is derived using Mat Lab software. From the research results, we can state that the phosphor size significantly affects the lighting performance of the 7000K IPP-WLEDs.

2. RESEARCH METHOD

2.1. Simulation Model

In this section, the in-cup packaging WLEDs is simulated by using the commercial Light Tools software based on the Monte Carlo ray-tracing method (Figure 1). In this physical model of WLEDs, the basic parameters of the in-cup packaging WLEDs are defined as below:

a) The reflector: 8 mm bottom length, a 2.07 mm height, and a 9.85 mm length.
b) The in-cup phosphor layer: the thickness of 0.08 mm covers the 9 LED chips.
c) The LED chip: 1.14 mm square base and a 0.15 mm height. The radiant flux of each blue chip is 1.16 W at wavelength 455 nm.

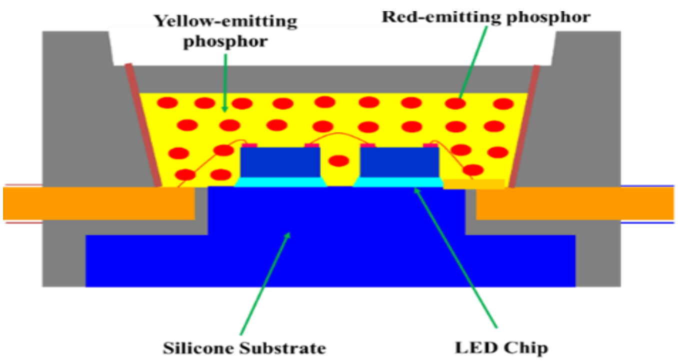

Figure 1. The 7000K IPP-WLEDs physical structure

2.2. Mathematical Analysis

In this section, applying Mie theory [16-18, 21-25], the coefficients of the scattering process of the phosphor layer of the in-cup packaging WLEDs can be calculated as the below expressions:

A. The scattering coefficient $\mu_{sca}(\lambda)$:

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

Where *N(r)* (mm^3) is the distribution density of diffusional particles. *N(r)* is composed of the diffusive particle number density $N_{dif}(r)$, and the phosphor particle number density $N_{phos}(r)$ can be presented as:

$$N(r) = N_{dif}(r) + N_{phos}(r) = K_N.[f_{dif}(r) + f_{phos}(r)] \tag{2}$$

Moreover, C_{sca} (mm^2) is the scattering cross-sections. In Mie theory, C_{sca} can be obtained by the following expression:

$$C_{sca} = \frac{2\pi}{k^2} \sum_{0}^{\infty} (2n-1)(|a_n|^2 + |b_n|^2) \tag{3}$$

Here λ (nm) is the light wavelength, and r (µm) is the radius of diffusional particles.

B. The anisotropy factor $g(\lambda)$,

$$g(\lambda) = 2\pi \int \int_{-1}^{1} p(\theta, \lambda, r) f(r) \cos\theta d \cos\theta dr \quad (4)$$

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

$f(r))$ is the size distribution function of the diffuser in the phosphor layer,

θ (°) is the scattering angle.

C. The reduced scattering coefficient $\delta_{sca}(\lambda)$:

$$\delta_{sca} = \mu_{sca}(1-g) \quad (5)$$

In these equations, $f(r)$ and $N(r)$ can be calculated by:

$$f(r) = f_{dif}(r) + f_{phos}(r) \quad (6)$$

Where $f_{dif}(r)$ and $f_{phos}(r)$ are the size distribution function data of the diffusor and phosphor particle.

3. NUMERICAL RESULTS AND DISCUSSION

In Figure 2, the scattering coefficient (SC) of the red phosphor crucial grew with increasing the red phosphor's size. The red phosphor has an excellent absorption ability for the blue light from LEDs. On another hand, the reduced scattering coefficient (RSC) of the red phosphor is the same with each other in depending on the concentration (Figure 3). It indicated that the scattering stability of the red phosphor showed great uses for controlling the color quality of the in-cup packaging WLEDs. From the analysis the scattering process in the phosphor layer of the in-cup packaging WLEDs, the results indicated that the involvement of the red phosphor into the phosphor compounding could play a major role in controlling the optical properties of the in-cup packaging WLEDs [16-18].

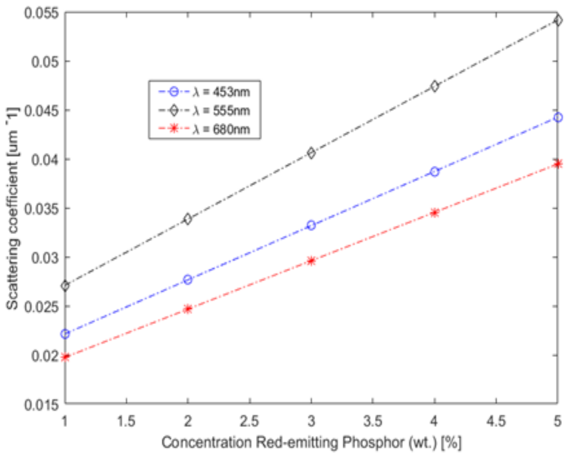

Figure 2. The scattering coefficient (SC)

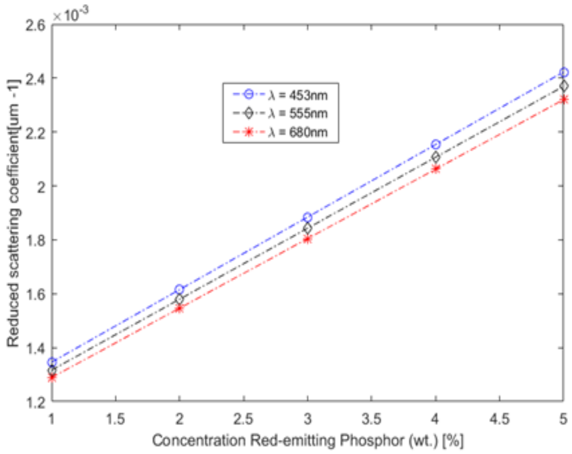

Figure 3. The reduced scattering coefficient (RSC)

Furthermore, the effect of the red phosphor size on the CRI and CQS of the 7000KIPP-WLEDs are drawn in Figure 6 and 7. In these cases, we set the size of the red phosphor from 4 µm to 10 µm. From the research results, we can see that the CRIrises from 52to 66 and the CQSincreases from 57 to 65 with the rising the red phosphor size, respectively. This effect can be caused by the more scattering processes in the phosphor layer, which leads to increasing the color quality of the IPP-WLEDs.

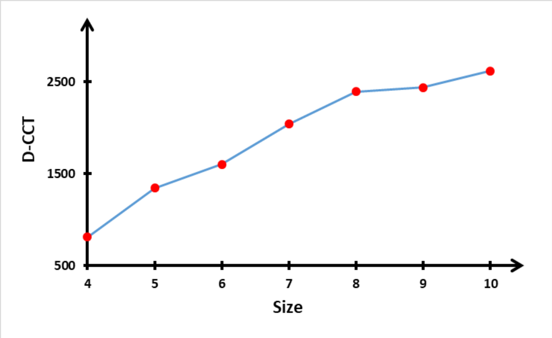

Figure 4. The D-CCT

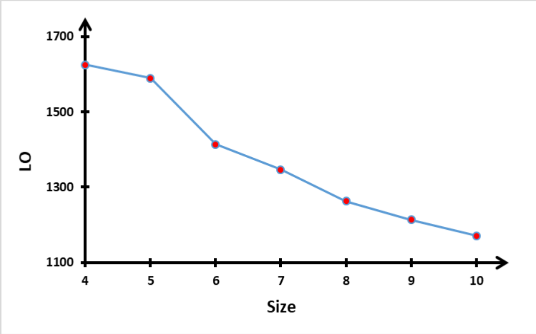

Figure 5. The lumen output (LO)

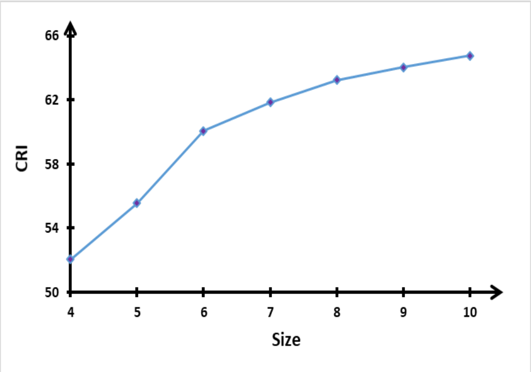

Figure 6. The CRI

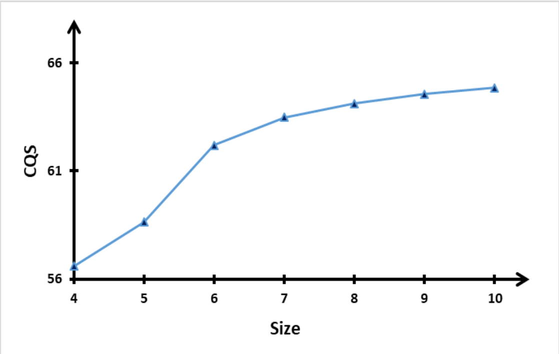

Figure 7. The CQS

4. CONCLUSION

In this paper, we built the simulation model of the 7000 K in-cup phosphor packaging white LEDs (IPP-WLEDs) by using the Light Tools software. After that, the effect of the Sr[Mg3SiN4]Eu2+ phosphor particle's size on the lighting performance in term of CCT Deviation (D-CCT), Color Rendering Index (CRI), Color Quality Scale (CQS), and Lumen Output (LO) is analyzed and investigated. Besides, the scattering processes in the phosphor layers of the 7000 K IPP-WLEDs is derived using Mat Lab software. From the research results, we can state that the phosphor size significantly affects the lighting performance of the 7000K IPP-WLEDs.

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