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$Ba[Mg_2Al_2N^4]Eu^{2+}$ PHOSPHOR FOR ENHANCING THE OPTICAL QUALITY OF THE 6600K CPW-LEDs

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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. In this paper, we proposed and investigated the effect of the concentration of Ba[Mg2Al2N4]Eu2+conversion phosphor on the CCT deviation (D-CCT) and lumen output (LO) of the 6600 K conformal-packaging white LEDs (CPW-LEDs). For this purpose, we used the Light Tools and Mat Lab software to investigate this problem. From the research results, we can state that the concentration of the red phosphor has a significant effect on the optical quality of the 6600 K CPW-LEDs. The D-CCT can be decreased from 4700K to 2500K, and the LO can be increased from 600 lm. to 1200 lm. This research can provide the new recommendation for LEDs industry at this time.

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1. Introduction

Conventional incandescent or fluorescent lamps have huge disadvantages due to the significant energy losses based on high temperatures performance and massive Stokes shifts. In comparison with the conventional lighting methods, light-emitting diodes (LEDs) based on spontaneous light emission in semiconductors with some excellent advantage such as superior lifetime, efficiency, and reliability can be considered as the next lighting generation [1-10]. In LEDs industry, we can generate the white light in three ways. Firstly, the white light is generated by mixing blue, green, and red colors LEDs. In a second way, the white light can be generated by using blue, green, and red phosphors in the phosphor layer LEDs. The last way, the white light can be generated by combining ultraviolet (UV) LEDs with blue, green, and red phosphors. In this paper, we investigate the second way with the following characteristics: (i) high conversion efficiency; (ii) high stability against chemical, oxygen, carbon dioxide, and moisture; (iii) low thermal quenching; (iv) small and uniform particle size (5–20 mm); and (v) appropriate emission colors [11-20].

In this paper, we proposed and investigated the effect of the concentration of Ba[Mg2Al2N4]Eu2+ conversion phosphor on the CCT deviation (D-CCT) and lumen output (LO) of the 6600 K conformal-packaging white LEDs (CPW-LEDs). For this purpose, we used the Light Tools and Mat Lab software to investigate this problem. From the research results, we can state that the concentration of the red phosphor has a significant effect on the optical quality of the 6600 K CPW-LEDs. The D-CCT can be decreased from 4700K to 2500K, and the LO can be

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increased from 600 lm. to 1200 lm. This research can provide the novel recommendation for LEDs industry at this time. The main contributions of our paper can be drawn as the followings

1. Light Tools conduct the physical model of the 6600K CPW-LEDs.
2. The scattering processes in the phosphor compounding of CPW-LEDs is investigated by Mat Lab.
3. The effect of the red phosphor concentration on the D-CCT and LO is investigated and convinced.

The rest of our paper can be presented in the following sections. The second section provides the physical model, scattering processes in the phosphor layer. The third section gives results and some discussions. The last section concludes this manuscript.

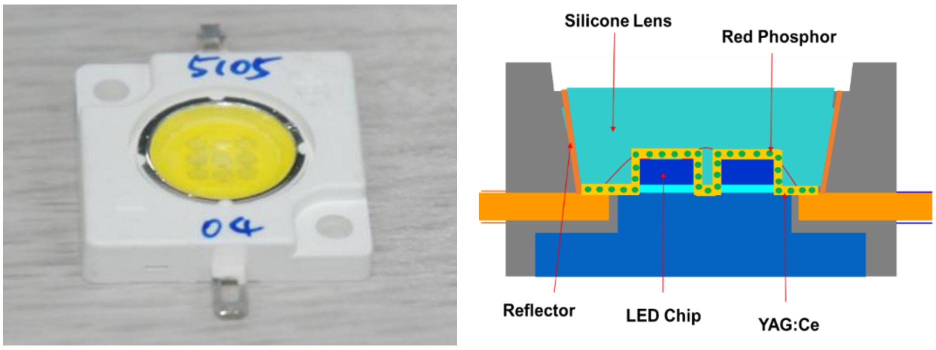
2. Research method

2.1. The CPW-LEDs physical model

In this section, we use the Light Tools to conduct the 6600K CPW-LEDs. In this simulation stage, we set the main parameters of the in-cup MCW-LEDs like below:

1) The depth, the inner and outer radius of the reflector to 2.07 mm, 8 mm and 9.85 mm, respectively.

2) Nine 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(Fig. 1(b)) [13-15].



(a) *(b)*

Fig.1. (a) The real WLEDs; (b) The physical model of the 6600K CPW-LEDs.

2.2.The scattering processes in the phosphor compounding

In this section, we use the Mie-scattering theory to investigate the scattering processes in the phosphor compounding of the CPW-LEDs as in [22-25]. 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):

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

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

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

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

In these equations, *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(θ,λ,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:

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

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

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:

$$c = K_N \int M(r)dr \tag{7}$$

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

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

Here $\rho_{diff}(r)$ and $\rho_{phos}(r)$ are the density of diffuser and phosphor crystal [26-30].

In Mie theory, C_{sca} and C_{abs} can be obtained by the following expressions:

$$C_{sca} = \frac{2\pi}{k^2}\sum_{0}^{\infty}(2n+1)(|a_n|^2 + |b_n|^2) \tag{9}$$

$$C_{ext} = \frac{2\pi}{k^2}\sum_{1}^{\infty}(2n+1)\,\mathrm{Re}(a_n + b_n) \tag{10}$$

$$C_{abs} = C_{ext} - \mathrm{C}_{sca} \tag{11}$$

where $k = 2\pi/\lambda$, and a_n and b_n are the expansion coefficients with even symmetry and odd symmetry, respectively. They can be calculated by:

$$a_n(x,m) = \frac{\psi_n^{'}(mx)\psi_n(x) - \mathrm{m}\psi_n(mx)\psi_n^{'}(x)}{\psi_n^{'}(mx)\xi_n(x) - \mathrm{m}\psi_n(mx)\xi_n^{'}(x)} \tag{12}$$

$$b_n(x,m) = \frac{m\psi_n^{'}(mx)\psi_n(x) - \psi_n(mx)\psi_n^{'}(x)}{m\psi_n^{'}(mx)\xi_n(x) - \psi_n(mx)\xi_n^{'}(x)} \tag{13}$$

where $x = k.r$, *m* is the refractive index, and $\psi_n(x)$ and $\xi_n(x)$ are the Riccati - Bessel function.

Moreover, the phase function $p(\theta,\lambda,r)$ can be calculated according to:

$$p(\theta,\lambda,r) = \frac{4\pi\beta(\theta,\lambda,r)}{k^2 C_{sca}(\lambda,r)} \tag{14}$$

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

$$\beta(\theta) = (1/2)[|S_1(\theta)|^2 + |S_2(\theta)|^2] \tag{15}$$

$$S_1(\theta)=\sum_{n=1}^{\infty}\frac{2n+1}{n(n+1)}[a_n\frac{P_n^1(\cos\theta)}{\sin\theta}+b_n\frac{dP_n^1(\cos\theta)}{d\theta}] \tag{16}$$

$$S_1(\theta)=\sum_{n=1}^{\infty}\frac{2n+1}{n(n+1)}[b_n\frac{P_n^1(\cos\theta)}{\sin\theta}+a_n\frac{dP_n^1(\cos\theta)}{d\theta}] \tag{17}$$

where $P_n^1(\cos\theta)$ is the associated Legendre polynomial [22-25].

3. Results and discussion

In this section, we investigate the scattering processes in the phosphor compounding of the 6600K CPW-LEDs by Mat Lab software. The scattering coefficient (SC) versus the concentration of the red phosphor is plotted in Fig.3. In Fig. 3, the SC of all increase significantly while the concentration of the red phosphor varies from 0% to 26%. This effect is caused by enhancing the white light quality in the CPW-LEDs by controlling the red phosphor concentration. Furthermore, the reduced scattering coefficient (RSC) with wavelengths 453nm, 555nm, and 680nm have illustrated in Fig. 4 with the increasing the concentration of the red phosphor from 0% to 26%. We can see that the RSC are the same as the red, yellow, and blue lights due to the scattering stability of red phosphor in the phosphor layer of the CPW-LEDs. Finally, the anisotropy coefficient (AC) versus the red phosphor concentration is plotted in Fig. 5. From the research results, we can state that the AC of the red and blue light is the same and are crucially lower than the AC of the yellow light.

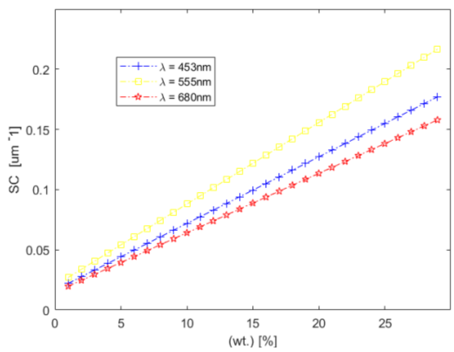


Fig. 3. Scattering coefficient (SC).

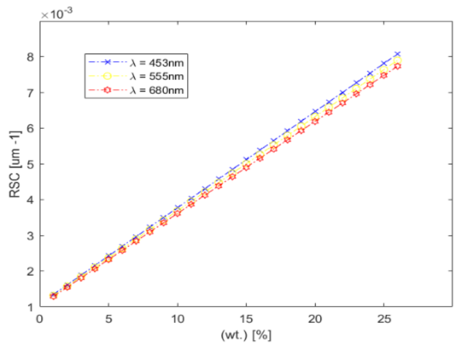


Fig. 4. Reduced scattering coefficient (RSC).

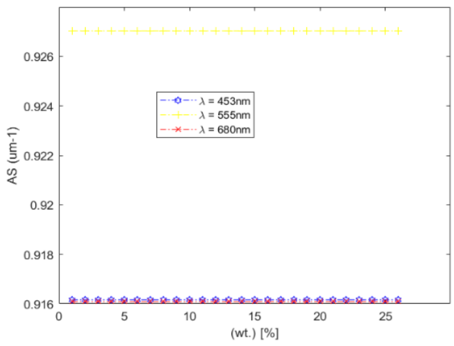


Fig. 5. Anisotropy coefficient (AC).

Furthermore, the D-CCT versus concentration of the red phosphor of the 6600k CPW-LEDs is illustrated in Fig. 7. In this Fig., the concentration of the red phosphor varies from 0% to 26% in the phosphor layer. As shown in Fig. 6, the D-CCT has a massive decrease from 4700K to 2500K when the concentration of the red phosphor varies from 0% to 26%. This effect is caused by the more scattering process on the phosphor compounding of the 6600K CPW-LEDs. Moreover, the effect of the concentration of the red phosphor on the LO of the 6600K CPW-LEDsis plotted in Fig. 7. From this Fig, we can see that the LO increases from 600 lm to 1300 lm with the increasing concentration from 0% to 26%. This effect can be caused by the more scattering and reduced scattering of the red phosphor particle in the phosphor layer.

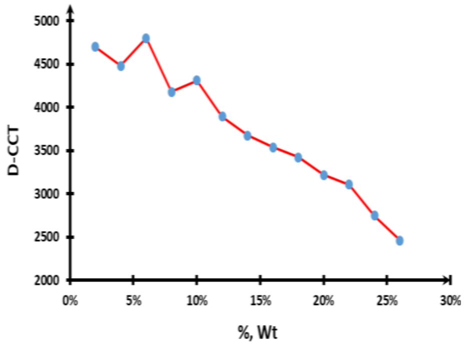


Fig. 6. The D-CCT.

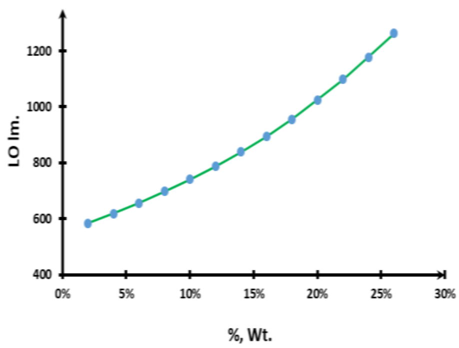


Fig. 7. The color quality scale (CQS).

4. Conclusions

In this paper, we proposed and investigated the effect of the concentration of Ba[Mg2Al2N4]Eu2+ conversion phosphor on the CCT deviation (D-CCT) and lumen output (LO) of the 6600 K conformal-packaging white LEDs (CPW-LEDs). For this purpose, we used the Light Tools and Mat Lab software to investigate this problem. From the research results, we can state that the concentration of the red phosphor has a significant effect on the optical quality of the 6600 K CPW-LEDs. The D-CCT can be decreased from 4700K to 2500K, and the LO can be increased from 600 lm. to 1200 lm. This research can provide the novel recommendation for LEDs industry at this time.

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