The usage of dual-layer remote phosphor configurations in enhancing color quality and luminous flux of WLEDs

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Abstract

Among conformal phosphor structure, in-cup phosphor structure, and remote phosphor structure, while in term of attaining the highest luminous flux, remote phosphor structure is the most ideal one, it seems to be that this structure results in the lowest-quality of color. Therefore, it is necessary in conducting experiments to surmount this disadvantage and make a possibility in enhancing the color quality of WLEDs with remote phosphor structure. In this research, with the ability of advancing the color rendering index (CRI) and color quality (CQS) for WLEDs, a dual-layer remote phosphor structure was considered as a suggestion. The experiments in this study used three kinds of WLEDs with the similar structures but different color temperatures varying at 5600 K, 7000 K, and 8500 K. The objectives of this paper is proposing a solution to obtain the highest color quality by placing a yellow-green emitting SrBaSiO₂:Eu²⁺ phosphor layer or a red-emitting SrₓFₓBi₂O₅:Eu²⁺,Sm²⁺ phosphor layer on the YAG:Ce³⁺ phosphor layer and then choosing the most appropriate value of SrₓFₓBi₂O₅:Eu²⁺,Sm²⁺ concentration. The experimental results which are satisfied expectations of researchers indicated that SrₓFₓBi₂O₅:Eu²⁺,Sm²⁺ has enforced its role in managing to raise the CRI and CQS. Particularly, the greater concentration of SrₓFₓBi₂O₅:Eu²⁺,Sm²⁺ leads to the higher the CRI and CQS, since the red light component in WLEDs increased. Besides, the quality of luminous flux is in a tight connection with the SrBaSiO₂:Eu²⁺ phosphor layer. Whereas, according to the Mie scattering theory and the Lambert-Beer law, if the concentration of SrₓFₓBi₂O₅:Eu²⁺,Sm²⁺ and SrBaSiO₂:Eu²⁺ becomes redundant, the luminous flux and color quality will take a deep dive. Briefly, the results from this article has largely contributed to fabricating high-quality WLEDs.

Keywords: color rendering index, lambert-beer law, luminous efficacy, white LED

1. Introduction

These days, the traditional light sources cannot meet the increasing and complicating demand for lighting, and become obsolete; thus, there is a need in getting the traditional light sources supplanted by other state-of-the-art ones. In an effort to fulfill this purpose, phosphor converted white light emitting diodes (pc-WLEDs), the fourth potential generation light source, was invented to become the superior in the illumination market and extend its application in different fields of our daily life such as landscape, street lighting, backlighting, etc [1-3]. However, the obstacles preventing the white LED from reaching its integrity are the limitations in light extraction efficiency and angular homogeneity of correlated color temperature. Hence, it is essential to eliminate these two problems to be able to expand the consumption market and make the best use of the advantages of white LEDs. Furthermore, one of the most optimum measures for the white light generation, so far, is the combination between the blue light from converse red phosphor and the yellow light from LED chip [4-7]. Although this idea is likely to be familiar, the importance of the structure of LEDs and the arrangement of phosphor layers in altering the luminous efficiency, especially the color rendering index, is undeniable. There are some suggested common phosphor coating methods in manufacturing LEDs such as dispensing coating and conformal coating [8-11]. Nevertheless, these common methods could not get the color quality reached the highest degree as the ability of the light conversion of
phosphor material is reduced due to the yellow emitting phosphor directly contacting with the LED chip, leading to the growth in temperature at the junction point of the LED and phosphor layer. Therefore, to assure that the phosphor’s performance is improved, and the phosphor is protected from damaging, the method is decreasing the degree of heat by setting up the phosphor away from the heat source (LED chip) [12-14]. If the phosphor is placed in an appropriate distance to the LED chips, we could limit the event of the backscattering and light circulation inside LED [15-17]. Thus, it could be concluded that this approach is an optimal solution to manage the temperature of LED, and improve the luminous efficiency as well as the LEDs’ color quality. Nevertheless, the remote phosphor structure can only meet the requirements of regular lighting, which might be the reason why there is a need of producing the next generation of LED. For further advancement, the backscattering of phosphors to the chip must be minimized and the illumination efficiency must be magnified through some structures. Another study pointed out that it is possible to redirect the light from the LED chip to the surface of the LED and then minimize the loss because of the internal reflection inside the LED with an inverted cone lens encapsulant and a surrounding ring remote phosphor layer [18, 19]. Moreover, with a clear region in the perimeter area without coating phosphor on the surrounding surface, a patterned remote phosphor structure could attain high uniformity of angular-dependent correlated color temperature and chromatic stability [20, 21]. Furthermore, the correlated color temperature uniformity could be lifted to a higher degree in a far field pattern than a conventional one, when the patterned sapphire substrate is added to the remote phosphor. Hence, for achieving the better light output of LEDs, remote phosphor with dual layer package is proposed. Though, in previous mentioned studies, the color uniformity and the output luminous flux improvement of WLEDs with phosphorus remote structure was also focused, the experiments were still carried out with the single chip WLEDs and low values of color temperatures, leading to the limitations in fulfilling their objective. Besides, raising the optical parameters for WLEDs with higher color temperature is a complex issue. In addition, the preferences used to compare the performance of different kinds of dual-layer phosphor configurations have remained unavailable. Thus, the challenge raised for manufacturers is how to determine the most optimal method for the color quality or the output luminous flux enhancement of WLEDs.

While the first idea was aimed to the increase of the green light component in WLEDs by applying the SrBaSiO$_4$:Eu$^{2+}$ green phosphor layer in order to promote the photon emission, in the second idea, the application of the red phosphoric layer Sr$_{w}$F$_{x}$B$_{y}$O$_{z}$:Eu$^{2+}$,Sm$^{2+}$ served the purpose of getting the amount of red light component in WLEDs grown, from which CRI and CQS reach the upper level. Additionally, detailed descriptions of the chemical composition of Sr$_{w}$F$_{x}$B$_{y}$O$_{z}$:Eu$^{2+}$,Sm$^{2+}$ as well as their effects on the optical properties of WLEDs are also included in the article. According to the results from the article, the increase in CRI and CQS could be assured by adding the Sr$_{w}$F$_{x}$B$_{y}$O$_{z}$:Eu$^{2+}$,Sm$^{2+}$ phosphor layer. Nonetheless, as mentioned above, the concentration of SrBaSiO$_4$:Eu$^{2+}$ and Sr$_{w}$F$_{x}$B$_{y}$O$_{z}$:Eu$^{2+}$,Sm$^{2+}$ should be controlled in an appropriate amount to avoid sharply declining the color quality or the output luminous flux sharply, when the concentration of green or red phosphors is lifted. As the yellow YAG:Ce$^{3+}$ phosphor layer is added the green or red phosphor layer, it is noticed that there are two unignorable differences. First, as the green or red light grows, the white light spectra increases, leading to the advance of color quality. Second, the direction of the concentration of additional phosphors determines the scattering and light transmission in WLEDs. Therefore, the suitable selection for the phosphor concentration plays a crucial role in maintaining the photosensitive performance of WLEDs.

2. Preparation

2.1. Preparation of SrBaSiO$_4$:Eu$^{2+}$ and Sr$_{w}$F$_{x}$B$_{y}$O$_{z}$:Eu$^{2+}$,Sm$^{2+}$ Particles

Particles of SrBaSiO$_4$:Eu$^{2+}$ and Sr$_{w}$F$_{x}$B$_{y}$O$_{z}$:Eu$^{2+}$,Sm$^{2+}$, a type of yellow-green phosphor famous for its remarkable features including high quantum efficiency and stability at high temperature, have gained their popularity in this field. Furthermore, the application of SrBaSiO$_4$:Eu$^{2+}$ and Sr$_{w}$F$_{x}$B$_{y}$O$_{z}$:Eu$^{2+}$,Sm$^{2+}$ phosphor is concentrated on very high-loading and long life-time fluorescent lamps.

Table 1 and Table 2 demonstrated the chemical composition of SrBaSiO$_4$:Eu$^{2+}$ and Sr$_{w}$F$_{x}$B$_{y}$O$_{z}$:Eu$^{2+}$,Sm$^{2+}$, considered as one of the elements greatly affecting the phosphor's optical
properties. Hence, it is important to analyze each component to apply these phosphors in WLEDs production. At the peak wavelength of 2.36 eV, yellow-green light is emitted from SrBaSiO$_4$:Eu$^{2+}$; and the illumination efficiency of SrBaSiO$_4$:Eu$^{2+}$ is risen due to the contribution of Eu$^{2+}$ ions. In contrast, Sr$_9$F$_3$B$_2$O$_7$:Eu$^{2+}$,Sm$^{2+}$ emits red light at diverse values of the peak wavelength including 684, 693, 697, 703, 723, 725, or 732 nm. Similar to Eu$^{2+}$, the presence of Sm$^{2+}$ ion gets the absorption gone up at varied peak values of 395, 420, and 502 nm. Therefore, the effectiveness of the red phosphor Sr$_9$F$_3$B$_2$O$_7$:Eu$^{2+}$,Sm$^{2+}$, or the optical is higher when the peak wavelength has more values.

![Table 1. Composition of Yellow-Green Emitting SrBaSiO$_4$:Eu$^{2+}$ Phosphor](image)

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<th>Ingredient</th>
<th>Mole (%)</th>
<th>By weight (g)</th>
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<th>Mole (mol)</th>
<th>Ions</th>
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<td>BaCO$_3$</td>
<td>31.79</td>
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<td>SiO$_2$</td>
<td>33.40</td>
<td>63</td>
<td>60.08</td>
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<td>Eu$_2$O$_3$</td>
<td>0.32</td>
<td>3.5</td>
<td>351.926</td>
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<td>NH$_4$Cl</td>
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<td>5.4</td>
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<td>Sr(NO$_3$)$_2$</td>
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<td>SrF$_2$</td>
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<td>F$^{-}$</td>
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<td>H$_3$BO$_3$</td>
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<td>309.2</td>
<td>61.83</td>
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<td>Sm$_2$O$_3$</td>
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<td>2.09</td>
<td>348.72</td>
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<td>Eu$^{3+}$</td>
<td>0.03</td>
<td>0.0012</td>
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To be applied in the production process, these phosphors must have a spectrum compatible with blue light from the LED chip, which means there is a consistency of the absorption spectra of these phosphors and the spectrum of the blue chip. For instance, the appropriate range for Sr$_9$F$_3$B$_2$O$_7$:Eu$^{2+}$,Sm$^{2+}$ absorption spectrum to absorb the emitted light in different bands is from 250 nm to 502 nm due to the existence of both emitted blue light and converted yellow light from the yellow phosphor layer. Similarly, the range of absorption spectrum of SrBaSiO$_4$:Eu$^{2+}$ is wide, from 3.4 eV to 4.88 eV with over 70% absorption efficiency.

For the preparation of carrying out the optical simulation of the SrBaSiO$_4$:Eu$^{2+}$ and Sr$_9$F$_3$B$_2$O$_7$:Eu$^{2+}$,Sm$^{2+}$ components, the input parameters including phosphorus concentration, size of phosphor particles, excitation spectrum, spectral absorption, and emission spectra of phosphors should be exactly set by conducting experiments. Among those parameters mentioned above, the concentration and the size of the phosphor are vital to get the best color and luminous flux of LED. In fact, the parameters of spectrum are constant. Based on the results of aforementioned researches, the phosphoric particles were set at fixed value of 14.5 μm in diameter. However, there was an adjustment in the concentrations of SrBaSiO$_4$:Eu$^{2+}$ and Sr$_9$F$_3$B$_2$O$_7$:Eu$^{2+}$,Sm$^{2+}$ phosphors to determine the optimum value.

2.2. Construction of Green-Yellow Dual-Layer Phosphor Configuration and Red-Yellow Dual-Layer Phosphor Configuration

Figure 1 (a) illustrates the actual WLEDs with 9 internal LED chips applied in this research. Each blue chip has the output value of 1.16W which reaches the peak at 453 nm. In Figure 1 (b), there is the LED profile specifications’ details. For figuring out the optimal value of SrBaSiO$_4$:Eu$^{2+}$ and Sr$_9$F$_3$B$_2$O$_7$:Eu$^{2+}$,Sm$^{2+}$ concentration, the remote phosphor model need to be constructed in the next step. Suggestions for the remote phosphor model in this study are two models of green-yellow dual-layer phosphor configuration (GYC) and red-yellow dual-layer phosphor configuration (RYC). In the GYC structure, there are two phosphor layers placed on the blue chips. The layer of SrBaSiO$_4$:Eu$^{2+}$ phosphor is above the yellow YAG:Ce$^{3+}$ phosphor layer, which is illustrated in Figure 1 (c). Demonstrated in Figure 1 (d) is the RYC structure, consisting of two phosphor layers covering the blue chips. Sr$_9$F$_3$B$_2$O$_7$:Eu$^{2+}$,Sm$^{2+}$ phosphor layer...
is put on the yellow YAG:Ce³⁺ phosphor layer. The application of GYC and RYC configurations aims at the enhancement of the color and the output luminous flux of WLEDs resulting from the rise in the scattering and composition of both green light and red light in WLEDs. However, the compatible calibration in the schema of SrBaSiO₄:Eu²⁺ and SrₓₓFₓₓBₓₓOₓₓ2:Eu²⁺,Sm²⁺ is essential to carry out.

**Figure 1.** Illustration of pcWLEDs: (a) the actual WLEDs and (b) its parameters; (c) illustration of GYC, and (d) RYC

As in Figure 2, the opposition in the change of the phosphor concentration between the green phosphor SrBaSiO₄:Eu²⁺ and the red phosphor SrₓₓFₓₓBₓₓOₓₓ2:Eu²⁺,Sm²⁺, in accordance with the yellow phosphor YAG:Ce³⁺, is described. This difference remains the average CCTs having effects on the scattering and absorption of two phosphor layers in WLEDs, resulting in unavoidable impacts on the color quality and luminous flux generated by WLEDs. Therefore, the factor deciding the color quality of WLEDs is the selection of SrBaSiO₄:Eu²⁺ and SrₓₓFₓₓBₓₓOₓₓ2:Eu²⁺,Sm²⁺ concentrations. When raising the concentration of SrBaSiO₄:Eu²⁺ and SrₓₓFₓₓBₓₓOₓₓ2:Eu²⁺,Sm²⁺ by 2-20% wt. and 2-26% wt., YAG:Ce³⁺ concentration declined to maintain the stability of the average CCTs. Similar to WLEDs with different color temperatures of 5600 K, 7000 K, and 8500 K, this phenomenon has the same way applying.

**Figure 2.** The change of phosphor concentration of (a) GYC and (b) RYC for keeping the average CCTs
The usage of dual-layer remote phosphor configurations… (Thuc Minh Bui)

Figure 3 indicated that the Sr$_w$F$_x$B$_y$O$_z$:Eu$^{2+}$,Sm$^{2+}$ concentration obviously influences the transmittance spectrum of WLEDs. If the WLEDs are expected to be produced with high color quality, their luminous flux should be allowed to be reduced in a small amount. In the two ranges 420-480 nm and 500-640 nm of light, a rise in the intensity is likely to appear with the concentration of SrBaSiO$_4$:Eu$^{2+}$ forming a proof of the intensification in the photon emission. Additionally, the increase in the blue-light scattering in WLED advances the degree of the scattering in the phosphor layer and in WLEDs, which benefits the color uniformity as a result. Therefore, this result pointed out the importance of SrBaSiO$_4$:Eu$^{2+}$ application. Besides, the increase in red light spectrum, from 648 nm to 738 nm with Sr$_w$F$_x$B$_y$O$_z$:Eu$^{2+}$,Sm$^{2+}$ concentration, can be easily realized. Yet, this change is insignificant, if the spectrum of two ranges 420-480 nm and 500-640 nm is not in an upward trend. Noticeably, the spectrum improvement of 420-480 nm lifts the blue-light scattering higher. If the color temperature is higher, the emission spectra becomes higher and leads to the better performance in color and luminous flux. Hence, this result proved the vital role of Sr$_w$F$_x$B$_y$O$_z$:Eu$^{2+}$,Sm$^{2+}$. As managing the color quality WLEDs has been facing many obstacles, but Sr$_w$F$_x$B$_y$O$_z$:Eu$^{2+}$,Sm$^{2+}$ has an outstanding ability in magnifying the color quality of WLEDs without concerning low color temperature (5600 K) or high color temperature (8500 K).

Figure 3. Emission spectra of GYCs and RYCs at the average CCTs of 5600 K, 7000 K and 8500 K, in turn are shown in (a,b), (c,d), (e,f) respectively.
3. Computation and Discussion

In this study, to evaluate the degree of accurate colors of objects performed during the time lighting, the color rendering index is used. The imbalance among three main colors: blue, yellow, and green occurs as the green light component increase, leading to the influence on the color quality of WLEDs, and then reduce the accuracy in generated colors of WLEDs. As shown in Figure 4, the results indicated that the CRI declines when the SrBaSiO₄:Eu²⁺ remote phosphor layer presents. Nonetheless, if compared to CQS, which is more crucial and faces more struggles in enhancing, this result of CRI is acceptable. According to Figure 5, CQS is still stable with the SrBaSiO₄:Eu²⁺ concentration is less than 8%. Therefore, an ideal amount of concentration for SrBaSiO₄:Eu²⁺ phosphor to be perfectly applied in WLEDs production is 8%, after the emission flux is considered.

![Figure 4. The color rendering index as a function of the concentration of SrBaSiO₄:Eu²⁺ and SrₓFₓBᵧOₙ:Eu²⁺,Sm²⁺: (a) GYC and (b) RYC](image)

![Figure 5. The color quality scale as a function of the concentration of SrBaSiO₄:Eu²⁺ and SrₓFₓBᵧOₙ:Eu²⁺,Sm²⁺: (a) GYC and (b) RYC](image)

From Figure 4, the SrₓFₓBᵧOₙ:Eu²⁺,Sm²⁺ phosphor concentration causes the colorimetric index to go up at all average CCTs. This phenomenon occurs due to the absorption process of red phosphor. When the blue light from the LED chip is absorbed by the SrₓFₓBᵧOₙ:Eu²⁺,Sm²⁺ phosphor, they are converted in to red lights by the red phosphor particles convert. Not only the blue light, but SrₓFₓBᵧOₙ:Eu²⁺,Sm²⁺ particles also absorb the yellow light. However, the absorption of the blue light by the LED chip is stronger than the other because of the absorption properties of the material. Therefore, a higher color rendering index (CRI) can be achieved, when the SrₓFₓBᵧOₙ:Eu²⁺,Sm²⁺ is added and then gets the red light component in WLEDs risen. As the importance of the color rendering index in selecting WLED these days, it is obvious that the higher degree of the color rendering index results in the higher price of white light WLED. However, the production cost will be saved if the SrₓFₓBᵧOₙ:Eu²⁺,Sm²⁺ phosphor is applied in WLEDs fabrication.
In this way, the application of $\text{Sr}_w\text{F}_b\text{B}_r\text{O}_z\text{Eu}^{2+}\text{Sm}^{2+}$ in WLEDs manufactures could be widen. However, to give the best evaluation of the color quality of WLEDs, it is not just based on the CRI, which means when a WLED has a good color quality, its color rendering index does not need to be high. Hence, a new parameter known as color quality scale (CQS) is mentioned as a new proposal in this article. CQS is a metric system defined by three factors: the color index, the viewer’s preference, and the color coordinates. Due to using these three key factors, CQS has become a superior metric that can ascertain the overall color quality of WLEDs. In Figure 5, it is illustrated the CQS increases when there is the $\text{Sr}_w\text{F}_b\text{B}_r\text{O}_z\text{Eu}^{2+}\text{Sm}^{2+}$ remote phosphor layer, especially, a strong growth in the CQS occurs when the concentration of $\text{Sr}_w\text{F}_b\text{B}_r\text{O}_z\text{Eu}^{2+}\text{Sm}^{2+}$ rises.

It is undeniable that the $\text{Sr}_w\text{F}_b\text{B}_r\text{O}_z\text{Eu}^{2+}\text{Sm}^{2+}$ phosphor can lift the white light quality of WLEDs to higher degree with dual-layer phosphor structures, which seems to reach the edge of the objective of the research, color quality enhancement. On the other hand, the drawback in the output luminous flux of $\text{Sr}_w\text{F}_b\text{B}_r\text{O}_z\text{Eu}^{2+}\text{Sm}^{2+}$ should not be ignored. In this section, the mathematical model of the transmitted blue light and converted yellow light in the double-layer phosphor structure will be expressed and demonstrated, based on which it is able to get the LED efficiency greatly heightened. The expressions of the transmitted blue light and converted yellow light for single layer remote phosphor package with the phosphor layer thickness of $2h$ are shown as below:

\[ PB_1 = PB_0 \times e^{-2\alpha_{B1}h} \]  
\[ PY_1 = \frac{1}{2} \frac{PB_0}{\alpha_{B1}-\alpha_{Y1}} \left( e^{-2\alpha_{Y1}h} - e^{-2\alpha_{B1}h} \right) \]  

the transmitted blue light and converted yellow light for double layer remote phosphor package with the phosphor layer thickness of $h$ are expressed as:

\[ PB_2 = PB_0 \times e^{-2\alpha_{B2}h} \]  
\[ PY_2 = \frac{1}{2} \frac{PB_0}{\alpha_{B2}-\alpha_{Y2}} \left( e^{-2\alpha_{Y2}h} - e^{-2\alpha_{B2}h} \right) \]  

In these expressions, $h$ is the thickness of each phosphor layer. The subscripts “1” and “2” illustrate the single layer and double-layer remote phosphor package. $\beta$ indicates the conversion coefficient for blue light converting to yellow light, and $\gamma$ presents the reflection coefficient of the yellow light. $PB_0$ expresses the light intensities of blue light ($PB$) and yellow light ($PY$) from blue LED. $\alpha_{B1}, \alpha_{Y1}$ describe the fractions of the energy loss of blue and yellow lights during their propagation in the phosphor layer respectively.

In comparison with the single layer structure, the double-layer phosphor structure can significantly improve the lighting efficiency of pc-LEDs:

\[ \frac{(PB_2+PY_2)-(PB_1+PY_1)}{PB_1+PY_1} > 0 \]  

while the Mie-theory [22, 23] is applied in analyzing the scattering of $\text{Sr}_w\text{F}_b\text{B}_r\text{O}_z\text{Eu}^{2+}\text{Sm}^{2+}$ phosphor particle, and calculating the scattering cross section $C_{sc}$ for spherical particles as the expression below, the Lambert-Beer law [24, 25] is used to computed the transmitted light power:

\[ l = I_0 \exp(-\mu_{ext}L) \]  

In which, $I_0$ presents the incident light power, $L$ indicates the phosphor layer thickness (mm) and $\mu_{ext}$ is described as the extinction coefficient, which can be shown as: $\mu_{ext} = N_r C_{ext}$, where $N_r$ is known as the number density distribution of particles (mm$^{-3}$), and $C_{ext}$ (mm$^{-1}$) is the extinction cross-section of phosphor particles.

Obviously, from (5), the dual-layer remote phosphor can generate the better light output of WLEDs than the single-layer phosphor. Hence, this article gives an explicit piece of evidence about the output effectiveness of the dual-layer remote phosphor layer. Besides, the attaining emission strongly rose as the increase from 2% wt. to 20% wt in the concentration of...
SrBaSiO\(_4\):Eu\(^{2+}\) appeared, as illustrated in Figure 5. Whereas, the concentration of the Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) phosphor layer influenced the dual-layer remote phosphor door. Especially, based on the Lambert-Beer law, the attenuation coefficient \(\mu_{\text{ext}}\) is in proportion to the Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) concentration except the ratio of light to energy. Thus, when firmly attaching the thickness of both phosphor layers of WLEDs to a specific value, the increase in Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) concentration can decrease the photon emission.

Figure 6 presented a trend of decline in luminous flux at overall three average CCTs with the presence of the Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) concentration. It can be easily realized that when the concentration of Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) is lifted up to 26\%, the luminous flux exposed in a large decrease. Nevertheless, if the benefits of the Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) phosphor layer including CRI and CQS improvement, along with higher flux from the dual-layer remote phosphor compared to the single-layer phosphor layer (without the red phosphor layer) are taken into consideration, this downward trend is absolutely acceptable. The left issue is the appropriate amount of Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) concentration which depends on the intention of manufacturers when produce this WELDs in a large quantity.

4. Conclusion
In brief, this research paper give a detailed demonstration on how SrBaSiO\(_4\):Eu\(^{2+}\) phosphor and Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) impact CRI, CQS, and luminous flux of dual-layer phosphor structures. By applying the Mie’s scattering theory and the Lambert-Beer law, the article has consolidated the selection of Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) in advancing the color quality, while choosing SrBaSiO\(_4\):Eu\(^{2+}\) is consider as an approach in innovating WLEDs, which is applied for both low color temperature of 5600 K and high color temperatures above 8500 K WLEDs. Therefore, the outcomes from this study have reach the purpose of the improvement in the color quality of white light, which is considered as a complex challenge to the remote-phosphor structure. Yet, the drawback related to the emission of the flux still exits, which can be described that if the SrBaSiO\(_4\):Eu\(^{2+}\) or Sr\(_w\)Fe\(_x\)Ba\(_y\)O\(_z\):Eu\(^{2+}\),Sm\(^{2+}\) rapidly increase, the color quality or luminous flux will show a sharp decline. Thus, it is extremely vital to decide an appropriate concentration. Based on the goals that manufacturers desire to achieve, they could refer to the information provided in this paper to make the best decision, so that better quality WLEDs can be produced.

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