Improvement of Color Quality and Luminous Flux of WLEDs with Dual-Layer Remote Phosphor Configurations

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Abstract. *In comparison with the conformal phosphor or in-cup phosphor structure, remote phosphor structure has a superior luminous flux whereas its color quality is inferior to the others'. Due to this drawback, it is essential to conduct experiments to find the solution for the improvement of the color quality of WLEDs using remote phosphor structure. In this study, a dual-layer remote phosphor structure that is capable of enhancing the Color Rendering Index (CRI) and Color Quality Scale (CQS) for WLEDs was proposed. Three kinds of WLEDs with the similar structures but different color temperatures varying at 5600 K, 7000 K, and 8500 K are used in this article. The mission of this paper is to place a yellow-green emitting* $SrBaSiO_4{:}Eu^{2+}$ *phosphor layer or a red-emitting* $Sr_wF_xB_yO_z{:}Eu^{2+},Sm^{2+}$ *phosphor layer on the* $YAG{:}Ce^{3+}$ *phosphor layer and then select the most appropriate value of* $Sr_wF_xB_yO_z{:}Eu^{2+},Sm^{2+}$ *concentration to get the greatest color quality. Experimental results were exactly as expected since* $Sr_wF_xB_yO_z{:}Eu^{2+},Sm^{2+}$ *really succeeded in increasing CRI and CQS. Specifically, the larger the* $Sr_wF_xB_yO_z{:}Eu^{2+},Sm^{2+}$ *concentration, the higher the CRI and CQS, resulting from the increase of the red light component in WLEDs. Meanwhile, the quality degree of luminous flux depends tightly on the* $SrBaSiO_4{:}Eu^{2+}$ *phosphor layer. However, if the* $Sr_wF_xB_yO_z{:}Eu^{2+},Sm^{2+}$ *and* $SrBaSiO_4{:}Eu^{2+}$ *concentration exceeds, the luminous flux and color quality will have a tendency to drop off thanks to the theory of Mie scattering and the Lambert-Beer law. The result of this paper is a valuable reference in the production of high-quality WLEDs.*

Keywords

Color rendering index, dual-layer remote phosphor, Lambert-Beer law, luminous efficacy.

1. Introduction

Nowadays, as the demand for lighting is increasing and complex, the traditional light sources become obsolete and need to be replaced. In that situation, phosphor converted White Light Emitting Diodes (pc-WLEDs), the fourth potential generation light source, was invented to dominate the illumination market and become widespread in different fields of our daily life such as landscape, street lighting, backlighting, etc [1], [2] and [3]. However, there is still a limitation in light extraction efficiency and angular homogeneity of correlated color temperature which obstructs the white LED in developing its integrity. Therefore, in order to expand the consumption market as well as optimize the use of white LEDs, these two aforementioned shortcomings need to be removed. Moreover, combining the blue light from converse red phosphor with the yellow light from LED chip is considered as the optimal method for the white light generation [4] and [5]. Although this concept seems to be rather familiar, it cannot be denied that the structure of LEDs and the arrangement of phosphor layers play an essential role in determining the luminous efficiency, especially the color rendering index. Several common phosphor coating methods have been proposed to produce LEDs such as dispensing coating and conformal coating [6], [7] and [8]. Nevertheless, the color quality is still not able to reach higher degree because the yellow emitting phosphor directly contacting with the LED chip makes the light conversion of phosphor material fall down, with the result that the temperature goes up at the junction point of the LED and phosphor layer. Therefore, in order to enhance the phosphor's performance and avoid damaging the phosphor, this amount of heat should be reduced by placing the phosphor away from the heat source (LED chip). When the distance between the phosphor and the LED chips is large enough, the backscattering and light circulation inside LED can be limited [9] and [10]. This approach is an optimal solution to control the temperature of LED as well as enhancing the luminous efficiency and the LEDs' color quality. Nonetheless, the remote phosphor structure can only meet the requirements of regular lighting, which is probably the reason why the next generation of LED is needed to creating. For further development, it is necessary to minimize the backscattering of phosphors to the chip and advance the illumination efficiency through some structures. Another paper showed that an inverted cone lens encapsulant and a surrounding ring remote phosphor layer can redirect the light from the LED chip to the surface of the LED and then reduce the loss caused by internal reflection inside LED. A patterned remote phosphor structure with a clear region in the perimeter area without coating phosphor on the surrounding surface could achieve high uniformity of angular-dependent correlated color temperature and chromatic stability [11]. Moreover, the patterned sapphire substrate applied in the remote phosphor could deliver much better the uniformity of the correlated color temperature in a far field pattern than a conventional one [12]. Remote phosphor with dual layer package is proposed to improve the light output of LEDs. The aforementioned studies aimed to improve the color uniformity and the output luminous flux of WLEDs with phosphorus remote structure. However, the limitations still exist when these studies only focused on the single chip WLEDs and low values of color temperatures. Meanwhile, the enhancement of optical parameters for WLEDs with higher color temperature is a complex issue. Furthermore, there have still not been comparison studies available for the performance of different kinds of dual-layer phosphor configurations [13]. Hence, it is challenging for the manufacturers to choose the best method to improve the color quality or the output luminous flux of WLEDs.

The first idea focused on the use of the $SrBaSiO_4:Eu^{2+}$ green phosphor layer to increase the green light component in WLEDs, resulting in increased photon emission. In contrast, in the second idea, the red phosphoric layer $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ was used to increase the red light component in WLEDs, thereby increasing CRI and CQS. The article also details the chemical composition of $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ and their effects on the optical properties of WLEDs. The article's results show that CRI and CQS are increasing with the addition of the $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ phosphor layer. However, an appropriate concentration of $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ should be selected in order to avoid a sharp drop in color quality or the output luminous flux, as the concentration of green or red phosphors increases. There are two noticeable differences when the green or red phosphor layer is added into the yellow $YAG:Ce^{3+}$ phosphor layer. First, the rise in green or red light, leading to the increase in white light spectra, which is also the key to advance color quality. Second, the scattering and light transmission in WLEDs are in the direction of the concentration of additional phosphors. Therefore, the selection of suitable phosphor concentration becomes essential for the maintenance of photosensitivity of WLEDs.

2. Preparation

2.1. Preparation of $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ Particles

The influence of using $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ particles, a type of yellow-green phosphor with many outstanding features such as high quantum efficiency and stability at high temperature, have become more and more popular [14]. Moreover, $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ phosphor are applied particularly for very high-loading and long life-time fluorescent lamps.

As can be seen, Tab. 1 and Tab. 2 presented in detail the chemical composition of $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$, one of the factors having significant effects on the phosphor's optical properties. The analysis of each component is essential when these phosphors are applied in WLEDs manufacturing. $SrBaSiO_4:Eu^{2+}$ emits yellow-green light when the wavelength reaches the peak of 2.36 eV. The presence of Eu^{2+} ions makes the illumination efficiency of $SrBaSiO_4:Eu^{2+}$ increase. Whereas, $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ emits red light as the peak wavelength is at different values of 684, 693, 697, 703, 723, 725, or 732 nm. Similar to Eu^{2+}, the existence of Sm^{2+} ion makes the absorption increase at varied peak values of 395, 420, and 502 nm. The more the peak values, the more effective the red phosphor $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$, or the higher the optical gain.

The requirement for being applied in the manufacturing of these phosphors is to have a consistent spec-

Tab. 1: Composition of yellow-green emitting $SrBaSiO_4$:Eu^{2+} phosphor.

Ingredient	**Mole** (%)	**By weight** (g)	**Molar mass** ($g{\cdot}mol^{-1}$)	**Mole** (mol)	**Ions**	**Mole** (mol)	**Mole** (%)
$SrCO_3$	31.28	145	147.63	0.982	$\mathbf{Sr^{2+}}$	0.982	0.088
$BaCO_3$	31.79	197	197.34	0.998	$\mathbf{Ba^{2+}}$	0.998	0.090
SiO_2	33.40	63	60.08	1.049	$\mathbf{Si^{4+}}$	1.049	0.094
Eu_2O_3	0.32	3.5	351.926	0.01	$\mathbf{O^{2-}}$	8.068	0.726
NH_4Cl	3.22	5.4	53.49	0.101	$\mathbf{Eu^{2+}}$	0.02	0.002

Tab. 2: Composition of red-emitting $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} phosphor.

Ingredient	**Mole** (%)	**By weight** (g)	**Molar mass** ($g{\cdot}mol^{-1}$)	**Mole** (mol)	**Ions**	**Mole** (mol)	**Mole** (%)
$Sr(NO_3)_2$	10.09	126.98	211.63	0.6	$\mathbf{Sr^{2+}}$	0.6	0.0241
SrF_2	5.43	40.58	125.62	0.32	$\mathbf{F^{-}}$	0.646	0.0259
H_3BO_3	84.12	309.2	61.83	5	$\mathbf{B^{3+}}$	5	0.203
Eu_2O_3	0.25	5.28	351.93	0.015	$\mathbf{O^{2-}}$	18.665	0.748
Sm_2O_3	0.11	2.09	348.72	0.006	$\mathbf{Eu^{2+}}$	0.03	0.0012
$\mathbf{Sr_wF_xB_yO_z{:}Eu^{2+},Sm^{2+}}$					$\mathbf{Sm^{2+}}$	0.012	0.00048

trum with blue light from the LED chip. The absorption spectra of these phosphors must match the spectrum of the blue chip. For instance, the absorption spectrum of $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} in the range of 250 nm to 502 nm is suitable for absorbing the light emitted in different bands because there is not only the blue light emitted but also the yellow light converted from the yellow phosphor layer. Similarly, $SrBaSiO_4$:Eu^{2+} also has a wide absorption spectrum ranging from 3.4 eV to 4.88 eV with an absorption efficiency of over 70 %.

Before conducting the optical simulation of the $SrBaSiO_4$:Eu^{2+} and $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} components, the input parameters such as phosphorus concentration, phosphor particles' size, excitation spectrum, spectral absorption, and emission spectra of phosphorus should be accurately determined by experiment. In the above five parameters, the concentration and the size of the phosphor are critical for achieving the highest color and luminous flux of LED. In fact, the spectral parameters are constant. Based on the results of previous studies, the diameter of the phosphoric particles was fixed at an average value of 14.5 µm. Meanwhile, the concentrations of $SrBaSiO_4$:Eu^{2+} and $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} phosphors were adjusted to gain the optimal value.

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

Figure 1(a) showed the picture of WLEDs with 9 internal LED chips which is used in this study. The output of each blue chip is 1.16 W with the peak value emitted at 453 nm. The detail of LED profile specifications was illustrated in Fig. 1(b). To find the optimal concentration of $SrBaSiO_4$:Eu^{2+} and $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+}, the next step is to construct the remote phosphor model. In this study, two models of Green-Yellow dual-layer phosphor Configuration (GYC) and Red-Yellow dual-layer phosphor Configuration (RYC) were proposed.

The GYC structure consists of two phosphor layers placed on the blue chips. SrBaSiO4:Eu2+ phosphor layer is located above the yellow phosphide layer YAG:Ce^{3+}, see Fig. 1(c). In Fig. 1(d), the RYC structure includes two phosphor layers putting on the blue chips. $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} phosphor layer is placed above the yellow YAG:Ce^{3+} phosphor layer. The goal of using GYC and RYC configurations is to improve the color and the output luminous flux of WLEDs by increasing the scattering and composition of both green light and red light in WLEDs. However, the schema of $SrBaSiO_4$:Eu^{2+} and

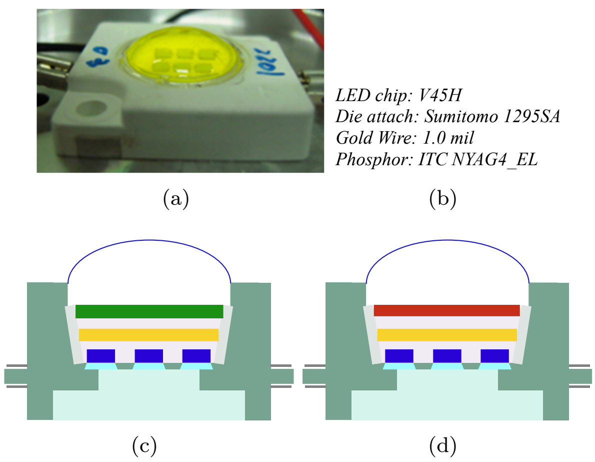


Fig. 1: Illustration of pcWLEDs: (a) The actual WLEDs and (b) its parameters; (c) Illustration of GYC, and (d) RYC.

$Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ needs to be calibrated accordantly.

Figure 2 depicted the opposite change between the green phosphor $SrBaSiO_4:Eu^{2+}$ concentration and the red phosphor $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ with the yellow phosphor $YAG:Ce^{3+}$. This difference maintains the average CCTs affects the scattering and absorption of two phosphor layers in WLEDs. This has inevitable effects on the color quality and luminous flux generated by WLEDs. Thus, the choice of $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ concentrations determines the color quality of WLEDs.

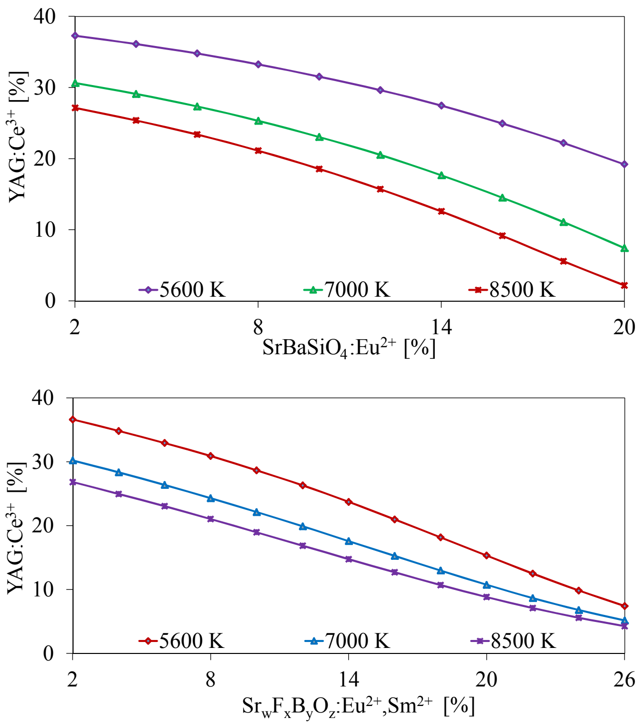


Fig. 2: The change of phosphor concentration of GYC (above) and RYC (below) for keeping the average CCTs.

When the concentration of $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ increased by 2–20 % wt. and 2–26 % wt., $YAG:Ce^{3+}$ concentration decreased to keep the average CCTs stable. This phenomenon is applied the same for WLEDs with different color temperatures of 5600 K, 7000 K, and 8500 K. The effects of $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ concentration on the transmittance spectrum of WLEDs as shown in Fig. 3 is the most noticeable. If the manufacturer requests the WLEDs to have high color quality, they must accept that a small amount of luminous flux can be reduced. The intensity in the two light areas of 420–480 nm and 500–640 nm has a tendency to increase with $SrBaSiO_4:Eu^{2+}$ concentration. This increase is the demonstration of the intensification in the emission of the photon. In addition, when the blue-light scattering in WLED increases, the scattering in phosphor layer and in WLEDs also goes up, resulting in the benefits for color uniformity. This is a very important result for $SrBaSiO_4:Eu^{2+}$. It is easy to see that red light spectrum has an increasing trend from 648 nm to 738 nm with $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ concentration. However, this is negligible unless there is a rise in the spectrum of two ranges 420–480 nm and 500–640 nm nm. The two-zone 420–480 nm spectrum enhancement makes the blue-light scattering higher. The higher the color temperature, the higher the emission spectra and thus, the color and luminous flux become better. This is a very important result for $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$. Typically, it is very difficult to control the color quality of WLEDs. However, $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ can improve color quality of WLEDs regardless of low color temperature (5600 K) or high color temperature (8500 K).

3. Computation and Discussion

In this article, the color rendering index is used to evaluate the true color of the object when the light is shining. The amount of green light goes up, which is the cause of the imbalance among three main colors: blue, yellow, and green. Consequently, the color quality of WLEDs is affected, resulting in the decrease of color accuracy of WLEDs. The results in Fig. 4 (above) show the reduction of CRI in the presence of the $SrBaSiO_4:Eu^{2+}$ remote phosphor layer. Nevertheless, this is still acceptable because compared to CRI, CQS is more vital and difficult to achieve. In Fig. 5, CQS does not change when the $SrBaSiO_4:Eu^{2+}$ concentration is less than 8 %. Hence, 8 % $SrBaSiO_4:Eu^{2+}$ is an ideal concentration when this phosphor is applied in WLEDs manufacturing after considering the emission of the flux.

As can be seen from Fig. 4 (below), the colorimetric index increases with the $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ phosphor concentration at all average CCTs. This is the result of the absorption of red phosphor. When $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ phosphor absorbs blue light from the LED chip, the red phosphor particles convert the blue light into red light. Beside the blue light from the LED chip, $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ particles also absorb the yellow light. However, in these two absorptions, the blue light absorbed by the LED chip is stronger due to the absorption properties of the material. Therefore, the red light component in WLEDs increases with the addition of $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$, resulting in a higher Color Rendering Index (CRI). In the current WLED selection, the color rendering index is one of the important parameters. Of course, the higher the color rendering index, the higher the price of white light WLED. However, if the

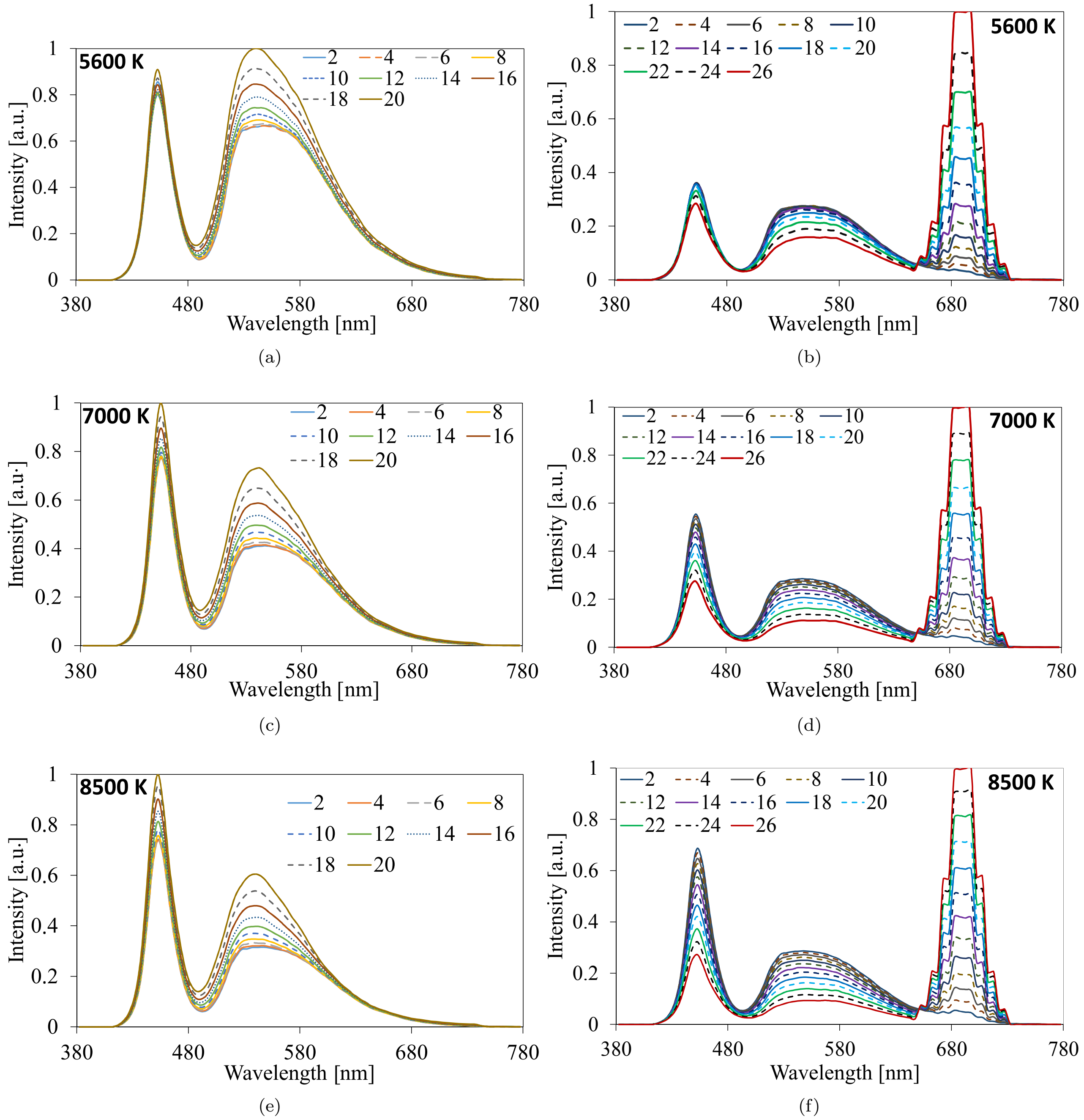


Fig. 3: Emission spectra of GYCs ((a), (c), (e)) and RYCs ((b), (d), (f)) at the average CCTs of 5600 K, 7000 K and 8500 K, in turn.

$Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} phosphor is used to produce WLEDs, the cost will be reduced considerably.

As a result, $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} can be widely applied to this manufacturing process. However, the color quality of WLEDs cannot be evaluated by only CRI. A WLED with good color quality does not mean it has a high color rendering index too. Therefore, this study provides a new parameter called Color Quality Ratio (CQS). CQS is an index defined by three factors: the color index, the viewer's preference, and the color coordinates [17] and [18]. With these three vital factors, CQS becomes a powerful index that can measure the overall color quality of WLEDs. Figure 5 (below) shows the elevation of CQS with the presence of the remote phosphor layer $Sr_wF_xB_yO_z$:Eu^{2+},$Sm^{2+}+$ and the sharp increase of CQS when the concentration of $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} appears. Obviously, using the $Sr_wF_xB_yO_z$:Eu^{2+},Sm^{2+} phosphor can improve the white light quality of WLEDs with dual-layer phosphor structures. This important result nearly reaches the aim of improving color quality of the study. How-

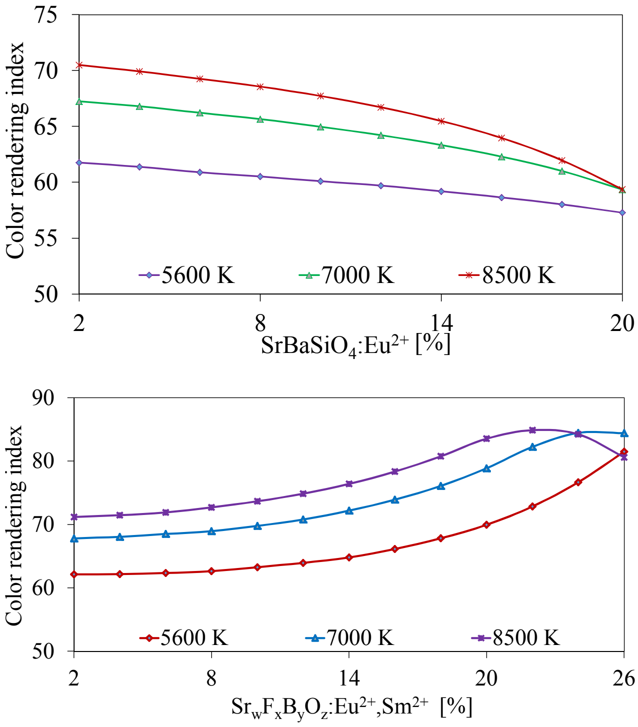


Fig. 4: The color rendering index as a function of the concentration of $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$: (above) GYC; (below) RYC.

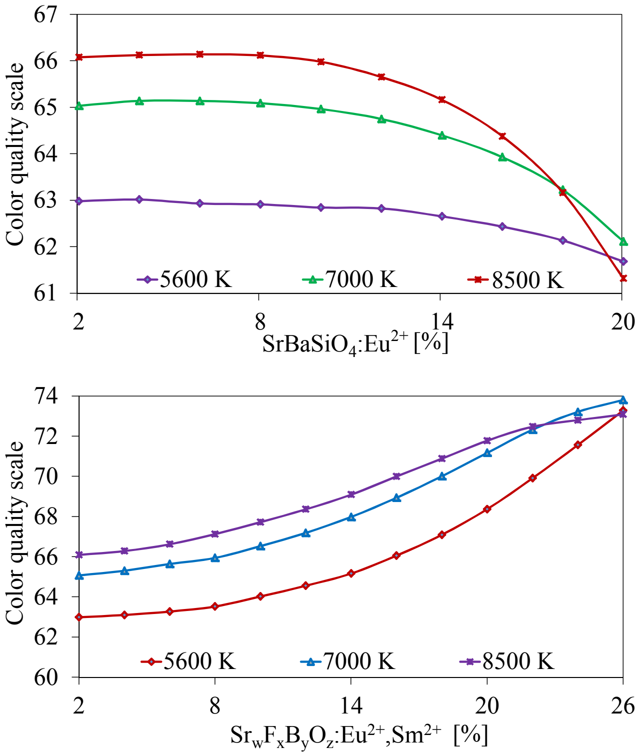


Fig. 5: The color quality scale as a function of the concentration of $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$: (above) GYC; (below) RYC.

ever, the disadvantage of $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ to the output luminous flux cannot be overlooked.

This part will present and demonstrate the mathematical model of the transmitted blue light and converted yellow light in the double-layer phosphor structure, from which a huge improvement of LED efficiency can be obtained. The transmitted blue light and converted yellow light for single layer remote phosphor package with the phosphor layer thickness of $2h$ are expressed as follows:

$$PB_1 = PB_0 \cdot e^{-2\alpha_{B1}h}, \tag{1}$$

$$PY_1 = \frac{1}{2}\frac{\beta_1 \cdot PB_0}{\alpha_{B1} - \alpha_{Y1}}\left(e^{-2\alpha_{Y1}h} - e^{-2\alpha_{B1}h}\right). \tag{2}$$

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

$$PB_2 = PB_0 \cdot e^{-2\alpha_{B2}h}, \tag{3}$$

$$PY_2 = \frac{1}{2}\frac{\beta_2 \cdot PB_0}{\alpha_{B2} - \alpha_{Y2}}\left(e^{-2\alpha_{Y2}h} - e^{-2\alpha_{B2}h}\right), \tag{4}$$

where h is the thickness of each phosphor layer. The subscript "1" and "2" are used to describe single layer and double-layer remote phosphor package. β presents the conversion coefficient for blue light converting to yellow light. γ is the reflection coefficient of the yellow light. The intensities of blue light (PB) and yellow light (PY) are the light intensity from blue LED, indicated by PB_0. α_B; α_Y are parameters describing the fractions of the energy loss of blue and yellow lights during their propagation in the phosphor layer respectively. The lighting efficiency of pc-LEDs with the double-layer phosphor structure enhances considerably compared to a single layer structure:

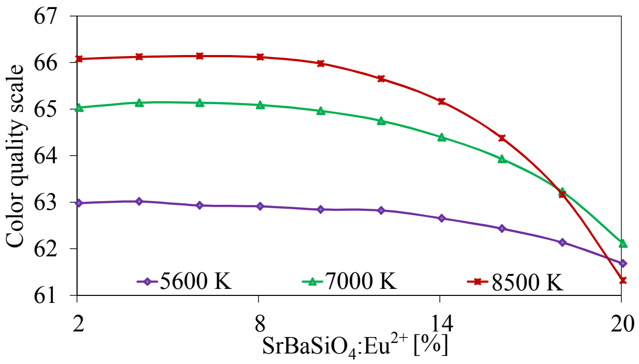
$$\frac{(PB_2 + PY_2) - (PB_1 + PY_1)}{PB_1 + PY_1} > 0. \tag{5}$$

The scattering of $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ phosphor particle was analyzed by using the Mie-theory [15] and [16]. In addition, the scattering cross section Csca for spherical particles can be computed by the following expression through applying the Mie theory. The transmitted light power can be calculated by the Lambert-Beer law:

$$I = I_0 e^{\mu_{ext} L}. \tag{6}$$

In this formula, I_0 is the incident light power, L is the phosphor layer thickness (mm) and μ_{ext} is known to be the extinction coefficient, which can be expressed as: $\mu_{ext} = N_r \cdot C_{ext}$, where N_r is as the number density distribution of particles (mm^{-3}). C_{ext} (mm^2) is the extinction cross-section of phosphor particles.

It can be seen from Eq. (5) that the light output of WLEDs with the dual-layer remote phosphor is greater than the single-layer phosphor. Thus, this paper demonstrates the effectiveness of the dual-layer remote phosphor layer's output. Figure 5 (above) showed that the resulting emission increased dramatically when $SrBaSiO_4:Eu^{2+}$ concentration increased from 2 % wt. to 20 % wt. However, the dual-layer remote phosphor door is affected by the concentration of the $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ phosphor layer. Noticeably, according to the Lambert-Beer law, the attenuation coefficient μ_{ext} is proportional to the concentration $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ except the ratio of light to energy. Therefore, when fixing the thickness of both phosphor layers of WLEDs, the photon emission can be reduced as $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ concentration increases.



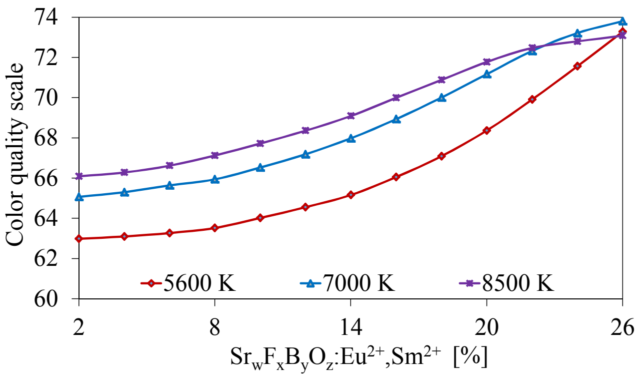


Fig. 6: The luminous flux as a function of the concentration of $SrBaSiO_4:Eu^{2+}$ and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$: (above) GYC; (below) RYC.

As predicted, Fig. 6 showed the decrease of luminous flux in overall three average CCTs. As the concentration of $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ is at 26 % of photosynthesis decreased extensively. However, if considering the advantages of the $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ phosphor layer including improved CRI and CQS, in addition, the flux of the dual-layer remote phosphor is also higher than the single-layer phosphor layer (without the red phosphor layer), this decline is completely acceptable. The remaining problem depends on the manufacturer's intention to select an appropriate concentration of $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ when mass production of this WELDs is conducted.

4. Conclusion

In conclusion, this paper presents the effects of $SrBaSiO_4:Eu^{2+}$ phosphor and $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ on CRI, CQS, and luminous flux of dual-layer phosphor structures. Based on Mie's scattering theory and the Lambert-Beer law, the study has proven that $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ is the right choice for bettering the color quality. Meanwhile, $SrBaSiO_4:Eu^{2+}$ is the choice for innovating WLEDs. This is not only applied for WLEDs with a low color temperature of 5600 K but also for those with color temperatures above 8500 K. Therefore, the results of this research have achieved the goal of improving the color quality of white light, which is very difficult for the remote-phosphor structure. However, there is still a slight disadvantage to the emission of the flux. If the increase of the $SrBaSiO_4:Eu^{2+}$ or $Sr_wF_xB_yO_z:Eu^{2+},Sm^{2+}$ levels is rapid, the color quality or luminous flux will decrease sharply. Consequently, selecting a suitable concentration becomes more important than ever. Depending on the manufacturer's purpose, the decision will be made to produce better quality WLEDs based on the information for reference this article provided.

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