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Research article

Improvement of Color Quality and Luminous Efficiency of Phosphor-Converted White Light by Enhancement of Red Spectral Composition

Huynh-Tuan-Anh Nguyen[a,b,*], Quang-Khoi Nguyen[a,b]

[a]*Faculty of Physics and Engineering Physics, VNUHCM-University of Science, Hochiminh City, Vietnam,*
[b]*Vietnam National University Hochiminh City, Hochiminh City, Vietnam.*

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* Corresponding author:

Huynh-Tuan-Anh Nguyen
E-mail: nhtanh@hcmus.edu.vn

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ABSTRACT

In this study, we studied a solution to improve the color quality and luminous efficiency of white LED by adding the red light composition. The effect of red light on the properties of white light at the CCT of 4500 K is investigated. Results show that the CRI value is changed depending on the added red light power. The maximum obtained CRI value is 96, which showed a significant improvement compared to the initial value of 71. The output luminous is increased which is proportional to the amount of added red light. The effect of red light on the change of CCT value, chromaticity coordinates, and Duv is also presented. The obtained result indicated that red LED mixed with pcW-LEDs is an efficient option that helps to improve the color quality and luminous efficiency of white LED.

1. INTRODUCTION

Solid state lighting (SSL) has replaced many traditional light sources due to its advantages such as high energy efficiency, long lifespan, vavid color, and environmentally friendly [1-3]. By using blue light-emitting diodes (LED) to excite the wavelength conversion material (e.g. yellow phosphor YAG:Ce), it generated a light mixture including un-absorpbed blue light and yellow light [3]. This light mixing causes the white feeling under the perception of human eyes. The white light LED that is generated by using this method is often called as the name of phosphor-converted white light emitting diodes or pcW-LEDs [4,5].

The yellow phosphor YAG:Ce used in the pcW-LEDs is famous due to its emission band having a high overlap level to the human eyes's sensitivity curve. This characteristic leads to a high luminous efficiency for pcW-LEDs when using YAG:Ce. The advantages in luminous efficiency lead to a big reducing in the color rendering index for the gennerated white light [3,6].

For general lighting applications, it is expected the CRI index higher than the value of 80. In some cases of lighting for fashion or art, the CRI is expected as high as 100 [6]. In terms of techniques, the continuous spectrum shows a higher CRI index than that of a discontinuous spectrum. The emission spectrum of pcW-LEDs dis-continuous spectrum types due to the low emission intensity of cyan wavelengths. In addition, the emission intensity of the red wavelength region is still weak. These characteristics limit the value of CRI for the white light of the pcW-LEDs. It thus posed a demand enhancement of the CRI value of white light to increase the lighting quality.

In this study, we studied a solution to improve the color quality and luminous efficiency of white LED by adding the red light composition. this method is a mixing method between red LED with pcW-LEDs. The quality improvement of the output properties of the white light with the CCT of 4500 K is conducted. In addition, the effect of red light on the change of CCT value, chromaticity coordinates, and Duv is also presented.

2. PROCEDURE OF IMPROVING THE COLOR QUALITY AND LUMINOUS EFFICIENCY OF WHITE LED

2.1 Selection of the emission spectrum of white light

First of all, the spectrum of warm white is simulated [7-9] and the parameters (CCT, CRI, and chromaticity coordinates) are defined [9-11]. Figure 1 shows the emission spectrum of pcW-LEDs in this study. The spectrum includes blue and yellow emission bands. The broader band is the yellow light emission band, and the narrower band is the blue emission band. The spectrum shows the blue light power is less than the yellow light power. The CCT value is 4358 K.

Figure 2 shows the value of each specific color rendering index of the emission spectrum of white light. The values for specific CRI1 to CRI15 are 62, 77, 95, 64, 63, 72, 85, 48, -51, 51, 58, 40, 65, 96, 49, respectively. The general CRI of the white light spectrum is 71. The general CRI value of this white light spectrum indicates a poor color rendering ability under the illumination of this white light.

Figure 3 shows the location of the color point of white light in color space. The location indicates the white light stays close to the warm white region. The value of chromaticity coordinates (CIEx, CIEy) is (0.3816, 0.4443). The location of the color point is closer to the horse shoes's outline which relates to the yellow light wavelength. Also, the location of color point in color space show the dominant of yellow light compare to blue light in the white light spectrum.

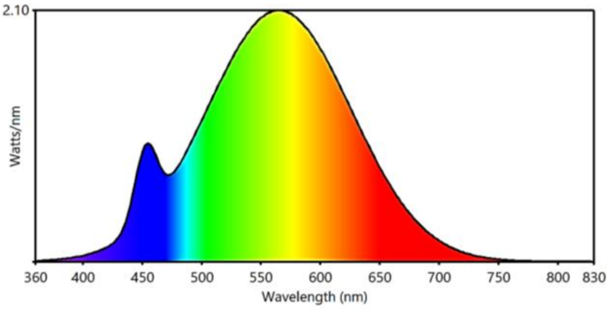

Fig. 1. The emission spectrum of white light in this study.

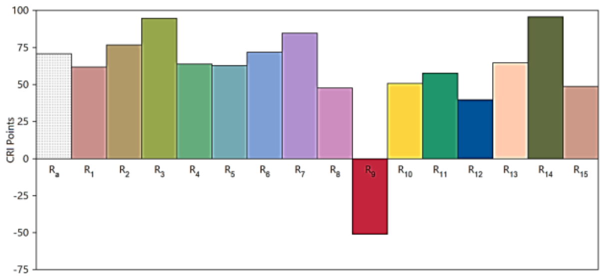

Fig. 2. The specific color rendering index of emission spectrum of white light.

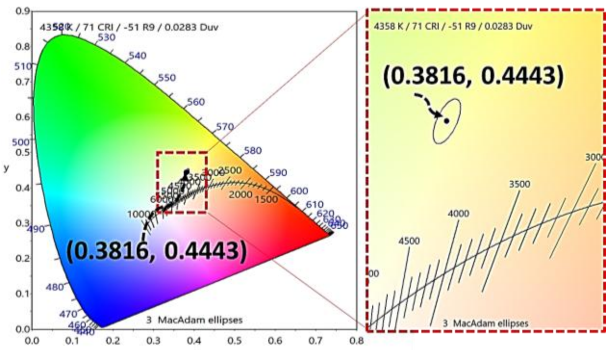

Fig. 3. Location of color point of white light in color space.

2.2 White light spectrum with adding red light at different power ratios

The white light spectrum in Fig. 1 is added red light spectrum. Then the optical properties of these spectra are defined and analyzed to find out the effect of red light on the changing of CRI and luminous efficiency. Figure. 4 shows the white light spectrum with adding red light at different power ratios. In all spectra, the ratio of blue and yellow light is normalized as the same ratios, while the added red light power is changed at different power ratios. In the simulation, different ratios of added red light from 2.6 to 5.6, corresponds to the interval increase of 0.2. The result shows a modification of spectra is mainly i n the wavelength range of 600 nm to 650 nm. After finishing adding red light power to the white light spectrum, the next step is calculating the parameters of CRI, output lumen, CCT, Duv, and the chromaticity coordinates.

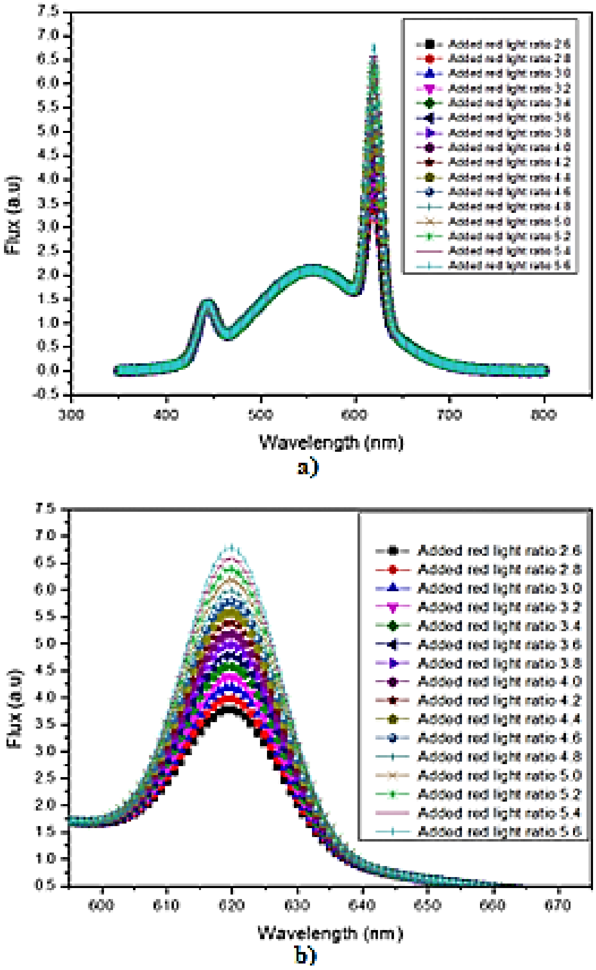

Fig. 4. (a) White light spectrum with adding red light at different power ratios. (b) enlarged spectra in the wavelength region 595 nm to 675 nm.

3. EFFECT OF RED LIGHT ON THE COLOR RENDERING INDEX AND OUTPUT LUMINOUS FLUX

Figure 5 shows the changing of CRI of the white light spectrum corresponding to different added red light power ratios as a function of the adding red light power ratios. The obtained results show a significant improvement in the CRI value by adding red light power into the white light spectrum. For the case without adding red light, the CRI value of the white light spectrum is 71. However, with adding red light power ratios 2.6, 2.8, 3.0, 3.2, 3.4, and 3.6, the CRI increased significantly from 71 to 90, 91, 92, 93, 94, and 95. For the case added red light power 3.8, 4.0, 4.2, 4.4, and 4.6, then the CRI values are as high as 96. This shows an optimal range of added red light power to reach the highest CRI value. However, when adding more red light (e.g. added red light power of 4.8, 5.0, 5.2, 5.4, 5.6), the CRI values show a decreasing tendency. The CRI value decreased from the value of 96 to 92.

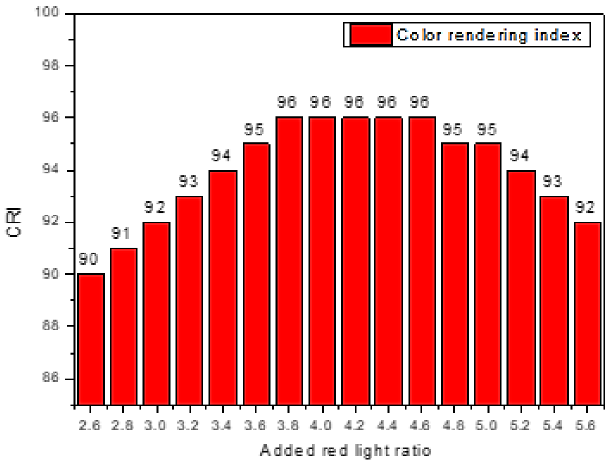

Fig. 5. CRI of white light spectrum is a function on the adding red light power ratios.

Figure 6 shows the changing of output luminous flux of the white light spectrum corresponding to different added red light power ratios as a function of the adding red light power ratios. The obtained results show a linearly increase of output lluminous flux as adding red light power into the white light spectrum.

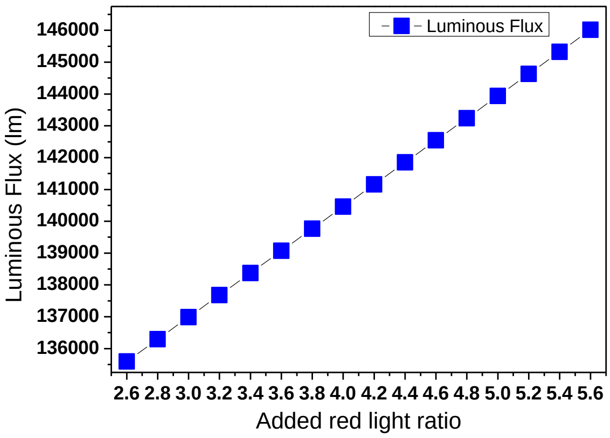

Fig. 6. Changing of output luminous flux corresponding to added red light power ratios.

4. EFFECT OF RED LIGHT ON THE CORRELATED COLOR TEMPERATURE AND CHROMATICITY PROPERTIES

Since the adding the red light cause a modification in the spectral power distribution of white light spectrum. As a result, the value of correlated color temperature will changed correspondently. The effect of added red light content to the CCT value of white light spectrum is shown in Fig. 7. The obtained result showed that, the larger the amount of red light, the lower the value of CCT is. The behavior of CCT versus added red light indicates that the adding red light is a faciliate way to control the CCT by adding more red light while still maintaining the blue and yellow light power content. For the same power ratio of blue and yellow light, different red light amounts are added including 0.0, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, and 4.6. Then, the corresponding CCT values are 4358 K, 3736 K; 3684 K; 3634 K; 3585 K; 3537 K; 3490 K; 3444 K; 3399 K; 3356 K; 3313 K; 3271 K; 3230 K; 3190 K; 3151 K; 3113 K; and 3076 K.

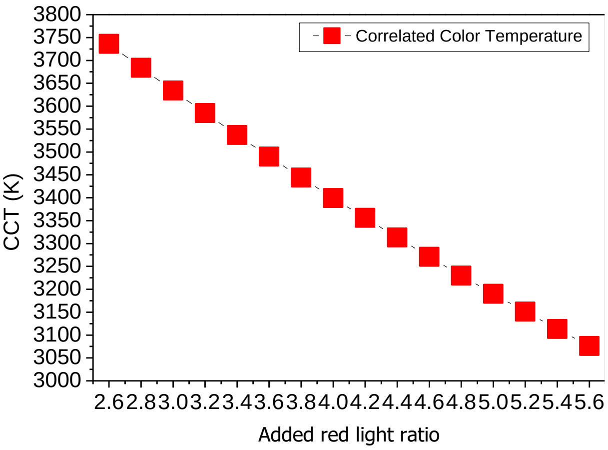

Fig. 7. Changing of corelated color temperature corresponding to added red light power ratios.

The effect of red light amount on the moving of color points is shown in Fig. 8. With adding red light, the color point coordinates is moved to the red light regions. In this study, the adding of red light is controled so that the distance of color point location is remained as close as to the black body radiation curve in the color space. The changing od Duv value versus the adding red light is shown in Fig. 9. It can see that the more red light be added, the closer of color point to the Plankian curve. It is remarkable that as the added red light amount of 4.2 to 5.6, the corresponded value of Duv is lesser than 0.005. Based on this behavior, one can selects the suitable amount of red light to add to white light spectrum to control the quality so that it still meet some standard for white light source before fabrication.

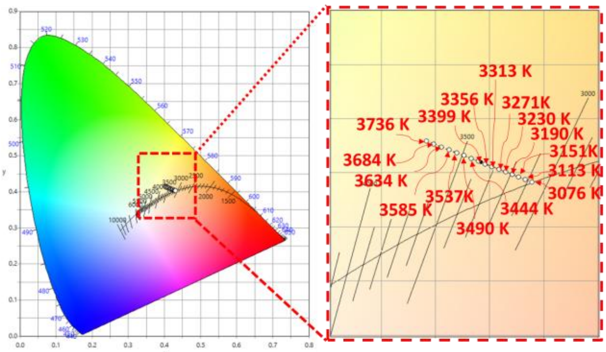

Fig. 8. Changing of color point's location corresponding to added red light power ratios.

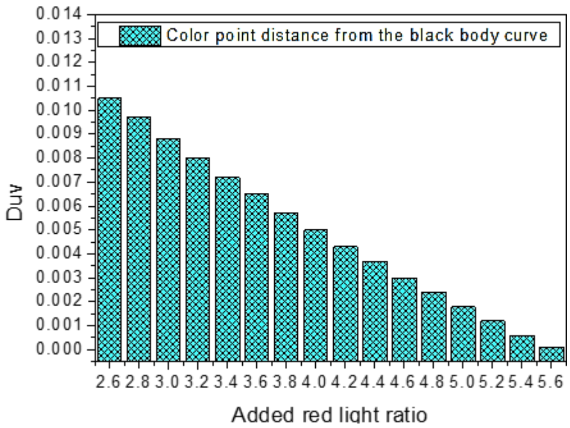

Fig. 9. Changing of Duv value corresponding to added red light power ratios.

5. CONCLUSION

In conclusion, we studied a solution to improve the color quality and luminous efficiency of white LED by adding the red light content. The effect of red light on the CRI and output luminous flux of white light at the CCT of 4358 K is investigated. The obtained result showed that, the initial value of 71 is significant improved to 96 with adding red light power 3.8, 4.0, 4.2, 4.4, and 4.6. Besides, the adding red light is also create more output luminous flux. The obtained results show a linearly increase of output lluminous flux as adding red light power into the white light spectrum. The adding of red light also affect to the CCT value, chromaticity coordinates, and Duv. The larger the amount of red light, the lower the value of CCT is. The behavior of CCT versus added red light indicates that the adding red light is a faciliate way to control the CCT by adding more red light while still maintaining the blue and yellow light power content. The effect of red light amount on the moving of color points showed that with adding red light, the color point coordinates is moved to the red light regions. It can see that the more red light be added, the closer of color point to the Plankian curve. It is remarkable that as the added red light amount of 4.2 to 5.6, the corresponded value of Duv is lesser than 0.005. The obtained result indicated that red LED mixed with pcW-LEDs is an efficient option that helps to improve the color quality and luminous efficiency of white LED.

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