

Luminous efficacy and color rendering index of high power white LEDs packaged by using red phosphor*

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Abstract: We packaged a series of high power white LEDs by covering the blue LED chips with yellow phosphor, red phosphor and the two phosphors mixed by appropriate mass ratio, respectively, and discussed the excitation and emission spectrum of yellow phosphor and red phosphor and the characteristics of the LEDs. We found that the luminous efficacy of the white LEDs covered with the two phosphors mixed by appropriate mass ratio was lower than that of the white LEDs covered with yellow phosphor, but the color rendering index was improved observably.

Key words: white LEDs; yellow phosphor; red phosphor; color rendering index; luminous efficacy; excitation spectrum

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1. Introduction

Light emitting diodes (LEDs) have been around for more than 30 years. This simple junction semiconductor emits continuous light when current flows through its junction at a low voltage^[1]. In recent years, there has been an increasing trend for white LEDs (W-LEDs) to replace the conventional incandescent and fluorescent lamps, due to their long lifetime, high energy efficiency, environmental protection and so on. White LEDs are believed to be the attractive “green lighting source of the 21st century” and show wide applications and a considerable prospective market^[2].

At present, W-LEDs are fabricated by combining one or two different types of phosphors that can be excited by the blue LED chip. However, white LED with yellow YAG:Ce phosphor excited by blue GaN has the following problems: white emitting color changes with input power, the mix-up of the two colors results in a low color rendering index and strong dependence of white color quality on an amount of phosphor leads to low reproducibility^[3, 4]. Color rendering is a property of a light source that shows how natural the colors of objects look under the given illumination. If color rendering is poor, the light source will not be useful for general lighting^[5]. The main driving force for solid-state lighting is the potential of huge energy savings on the national or global scale. Thus, when considering spectra of light sources for general illumination, another important aspect is luminous efficiency. The luminous efficiency of a source is determined by two factors: the conversion efficiency from electrical power to optical power and the conversion factor from optical power to luminous flux. The latter is called luminous efficacy.

As is well known, luminous efficacy and color rendering are determined solely by the spectrum of the source. But there is a fundamental trade-off relationship between luminous efficacy and color rendering, that is, one of the two quantities can be maximized only at the expense of the other. So, questions

arise on how the spectra of white LEDs should be designed for high luminous efficacy as well as good color rendering^[2].

Using red phosphor, the luminous efficacy and color rendering of high power white LEDs with yellow phosphor excited by blue GaN Chips are discussed and analyzed in this paper.

2. Experiment

We fabricated the high power white LED lamps by using high efficiency blue LED from the BridgeLux Company. The blue LED chips were p-side up mounted on a lead frame, covered with yellow phosphor, red phosphor and the two phosphors mixed by appropriate mass ratio, then the lead frames were molded in silica gel as the case of the lens. The excitation and emission spectra of the yellow phosphor and the red phosphor were measured at the F-4500 FL spectrophotometer of medium instrument lad of Chemistry College of Peking University at room temperature. The characteristics of the LEDs were measured under the HAAS-2000 high accuracy array spectrophotometer of Institute of Semiconductors, Chinese Academy of Sciences at 350 mA at room temperature.

3. Results and discussion

The excitation and emission spectra of yellow phosphor is shown in Fig. 1. It consists of a main excitation peaked at 467 nm and a main emission peaked at 530 nm. Figure 2 shows the excitation and emission spectra of red phosphor. It can be observed that a board excitation band from 470 to 550 nm and two emission spectra excited by 530 and 453 nm. Obviously, the intensity of the emission spectrum excited by 530 nm is more strongly than that excited by 453 nm because the excitation peaked is about at 530 nm.

Figure 3 shows the EL spectra of the white LEDs covered with yellow phosphor and red phosphor that operated at a forward current of 350 mA. For the covered with yellow phos-

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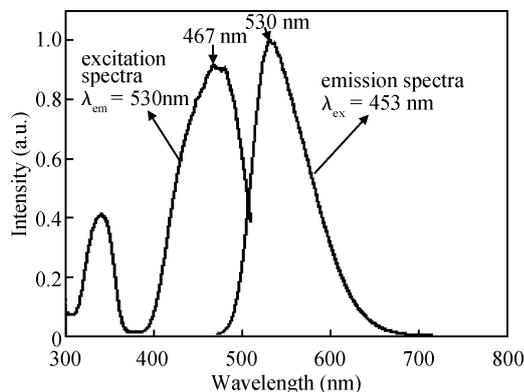


Fig. 1. Excitation and emission spectra of yellow phosphor.

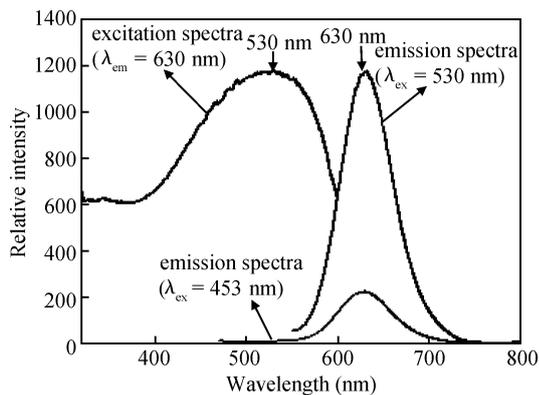


Fig. 2. Excitation and emission spectra of red phosphor.

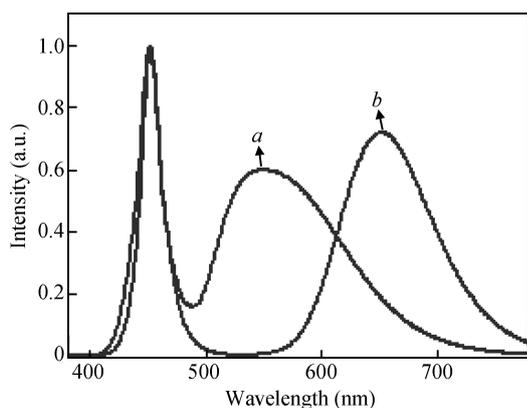


Fig. 3. EL spectra of covered with (a) yellow phosphor and (b) red phosphor white LEDs at 350 mA.

phor white LED, the luminous flux, V_f , CIE chromaticity coordinate x , y , CCT, luminous efficacy and R_a at 350 mA were 96.51 lm, 3.22 V, 0.3219, 0.3479, 5958 K, 85.62 lm/W and 72.8, respectively. For the covered with red phosphor white LED, the luminous flux, V_f , CIE chromaticity coordinate x , y , CCT, luminous efficacy and R_a at 350 mA were 18.87 lm, 3.27 V, 0.3632, 0.1528, 1528 K, 16.47 lm/W and -30.4, respectively. The luminous efficacy of the latter was lower than that of the former because the red phosphor cannot be efficiently excited by the blue LED chips.

A series of white LEDs were packaged by being covered

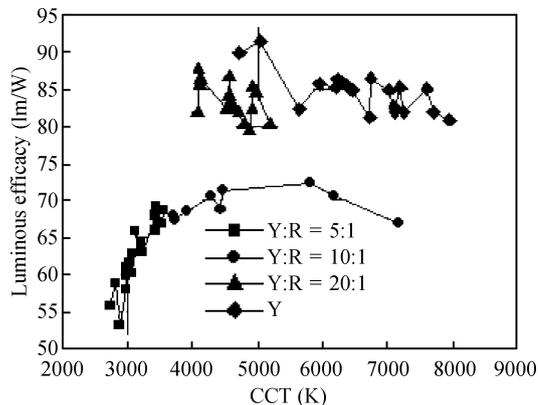


Fig. 4. Relationship of the luminous efficacy (lm/W) and CCT (K) of the series of white LEDs.

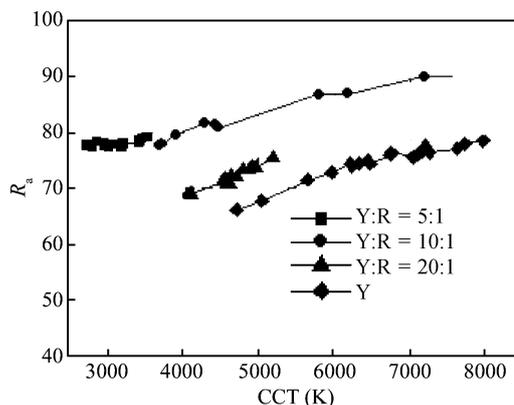


Fig. 5. Relationship of the color rendering index and CCT (K) of the series of white LEDs.

with the yellow (Y) and red (R) phosphors mixed by different mass ratio. Figure 4 shows the relationship of the luminous efficacy (lm/W) and CCT (K) of the series of white LEDs and Figure 5 shows the relationship of the color rendering index and CCT (K) of the series of white LEDs. It can be observed that the luminous efficacy decreased and the color rendering index improved observably along with the increase of the mass ratio of red phosphor. The color temperature of warm white LEDs could be under 3000 K, and the color rendering index of that could be close to 80.

The EL spectra of covered with yellow phosphor and the two phosphors mixed at the mass ratio of about 10 yellow phosphor : 1 red phosphor white LEDs at 350 mA are shown in Fig. 6. For the covered with yellow phosphor white LED, the luminous flux, V_f , CIE chromaticity coordinate x , y , CCT, luminous efficacy and R_a at 350 mA were 96.51 lm, 3.22 V, 0.3219, 0.3479, 5958 K, 85.62 lm/W and 72.8, respectively. For the covered with the two phosphors mixed at the mass ratio of about 10Y : 1R white LED, the luminous flux, V_f , CIE chromaticity coordinate x , y , CCT, luminous efficacy and R_a at 350 mA were 81.58 lm, 3.22 V, 0.3267, 5800 K, 72.36 lm/W and 86.9, respectively. The luminous efficacy of the latter was smaller than that of the former because of Stokes loss^[6]. The R_a of the latter was larger than that of the former because the dichromatic white LED with partial conversion can be im-

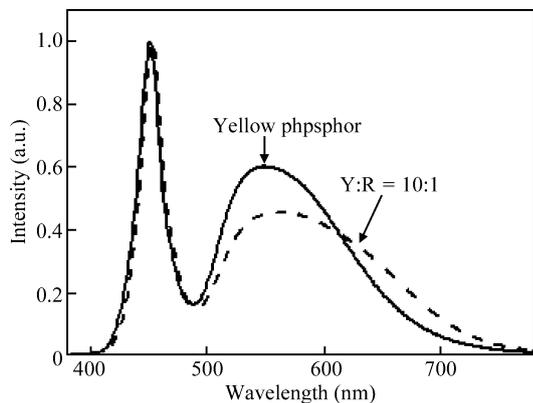


Fig. 6. EL spectra of covered with yellow phosphor and the two phosphors mixed at the mass ratio of about 10 yellow phosphor : 1 red phosphor white LEDs at 350 mA.

proved by supplementing it with red–orange and cyan-colored LEDs^[7, 8].

4. Conclusion

We packaged a series of high power white LEDs by covering the high efficiency blue LED from the BridgeLux Company with yellow phosphor, red phosphor and the two phosphors mixed by appropriate mass ratio, respectively, and measured the excitation and emission spectra of the yellow phosphor and the red phosphor and the characteristics of the LEDs at 350 mA at room temperature.

The luminous efficacy of the white LEDs covered with red phosphor was lower than that of the white LEDs covered

with yellow phosphor because the red phosphor cannot be efficiently excited by the blue LED chips.

Along with the increase of the mass ratio of red phosphor, we can observe that the luminous efficacy decreased because of Stokes loss, and that the color rendering index improved observably because the dichromatic white LED with partial conversion can be improved by supplementing it with red–orange and cyan-colored LEDs. The warm white LEDs with high color rendering index and low color temperature could be produced.

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