# White-light from NUV InGaN LED chip precoated with blue/yellow phosphors

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A white-light-emitting diode (WLED) was fabricated by precoating blue/yellow phosphors onto a near ultraviolet (NUV) LED chip. When the WLED operated under a direct current (DC) of 20 mA at room temperature, the color temperature $T_c$, the color-rendering index $R_a$, and the Commission Internationale de l'Eclairage chromaticity coordinate ($x$, $y$) are calculated to be 5998 K, 90.3 and (0.3253, 0.2822), respectively. With increasing DC from 10 to 40 mA, both the coordinates $x$ and $y$ of the WLED trend to decrease slightly, and consequently the $R_a$ and the $T_c$ decreases and increases, respectively. Compared with conventional "blue chip + yellow phosphor (YAG)" WLED, the "NUV chip + blue/yellow phosphor" WLED shows higher $R_a$.

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*Keywords:* Color-rendering index ($R_a$), Color temperature ($T_c$), White-light-emitting diode (WLED)

## 1. Introduction

White-light-emitting diodes (WLEDs) have been studied extensively and are called the novel generation solid-state light sources [1-4]. Currently, the WLED composed of a blue light-emitting-diode (LED) and a yellow-emitting phosphor (YAG: Ce) has been commercialized. This blue/yellow WLED, with characteristics of compact size, high efficiency, long lifetime, low power requirement, and energy savings, has been widely used in various applications such as liquid crystal display back lighting, full-color displays, cell phones, and traffic signals [5, 6]. However, this white light has a low color rendering index $R_a$ around 80 [7] (sunlight, the best white light for human beings, is defined as 100) since the light emitting from YAG: Ce is deficient in the red spectral region. To improve $R_a$, a red-enhanced YAG: Ce or a red phosphor was used in this blue/yellow WLED [7-9]. However, both species and quantity of red phosphors that can be excited efficiently by blue LED chips are scarce except for a few sulfide-based and nitride-based phosphors. Furthermore, there is another problem: sulfide phosphors are chemically unstable and poisonous, and the synthesis of nitride phosphors are complex due to high firing temperature (> 1600 °C) and high $N_2$ pressure (> 5 atm) [10, 11].

In recent years, remarkable progress has been made in the development of (Al, In)GaN chips with emission bands shifted to near-ultraviolet (NUV) range (350 – 420 nm). Compared with currently commercial WLED fabricated with a blue chip and a yellow phosphor (YAG: Ce), the WLED fabricated with an NUV chip and corresponding phosphors has higher efficiency and color rendering index [12-14]. In this work, a two-band WLED was fabricated using an NUV InGaN LED chip precoated with a blue phosphor $LiSrPO_4$: $Eu^{2+}$ and a yellow phosphor $Ba_2Mg(PO_4)_2$: $Eu^{2+}$. The phosphors $LiSrPO_4$: $Eu^{2+}$ and $Ba_2Mg(PO_4)_2$: $Eu^{2+}$ were prepared by previous method [15, 16]. The emission spectrum of this WLED was measured. Its Commission Internationale de I'Eclairage (CIE) chromaticity coordinate, color temperature $T_c$, and color rendering index $R_a$ were calculated.

## 2. Experimental

To fabricate the WLED, the blue phosphor and the yellow phosphor were mixed first, and then the mixed powder was blended with epoxy resin in order to be precoated on the LED chip. The thickness of the admixture precoated on the chip is the same due to the fixed size of the reflector cup. Another type of transparent epoxy resin was used to protect and fix the whole device, and the subsequent curing was done at 120 °C for 1 h. The fabrication of the blue LED or yellow LED followed the same steps as the WLED by using a single phosphor instead of their mixture. Emission spectra, chromaticity coordinates and correlated color temperature ($T_c$) of the fabricated LEDs were measured by PMS-50 LED spectrophotocolorimeter (EVERFINE, China). All measurements were operated at room temperature.

## 3. Results and discussion

Fig. 1 shows emission spectra of the blue LED, the yellow LED, and the white LED under a direct current (DC) 20 mA. The peak wavelengths of the blue, yellow emission in spectra (a), (b) and (c) are 449 and 588 nm, respectively. The peak wavelength of 449-nm blue emission and the broad emitting band peaked at 588 nm were originated from $LiSrPO_4$: $Eu^{2+}$ and $Ba_2Mg(PO_4)_2$: $Eu^{2+}$ that were excited by the NUV InGaN chip, respectively.

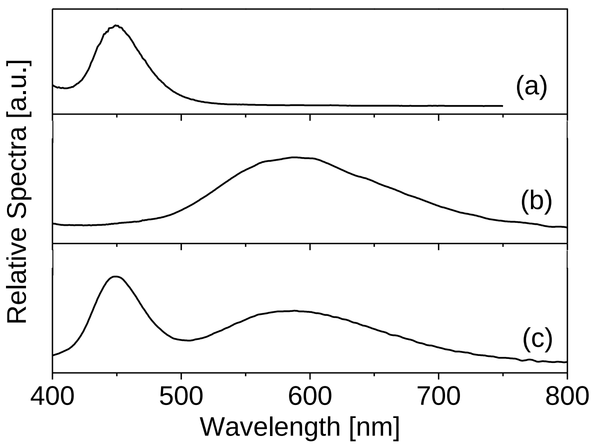


*Fig. 1. Emission spectra of the (a) blue LED, (b) yellow LED, and (c) white LED under a DC 20 mA.*

The coordinates calculated from the spectra in Fig. 1 are plotted in the CIE 1931 chromaticity diagram (see Fig. 2). As shown in Fig. 2, point E is equality energy white point, and its CIE chromaticity coordinate is (0.3333, 0.3333). The photoluminescence (PL) spectrum of the WLED is influenced by the ratio of the blue phosphor to the yellow phosphor. As the ratio of the blue phosphor to the yellow phosphor increases, more NUV light is absorbed by the blue phosphor and the 449-nm emission tends to be more intense, and consequently, the 588-nm emission tends to be weaker. The variety of the intensities of any emissions in the spectrum causes the change of the CIE chromaticity coordinate. As shown in Fig. 2, when the ratio of the blue phosphor to the yellow phosphor increases, point *c* moves toward point *a* along line *ab*, and *vice versa*. The two-band WLED can be generated through adjusting the ratio of the blue phosphor to the yellow phosphor. In this work, with appropriate ratio, the WLED was fabricated using “NUV InGaN LED Chip + blue phosphor + yellow phosphor”. When operated in a DC 20 mA, the CIE chromaticity coordinate of the prepared WLED locates in the white light region in CIE 1931 chromaticity diagram with $x = 0.3253$ and $y = 0.2822$. The color temperature $T_c$ and the color rendering index $R_a$ of the WLED are 5998 K and 90.3, respectively. The inset in Fig. 2 is a photograph of the lighting WLED under 20 mA current excitation. Bright white from the LED is observed by naked eyes.

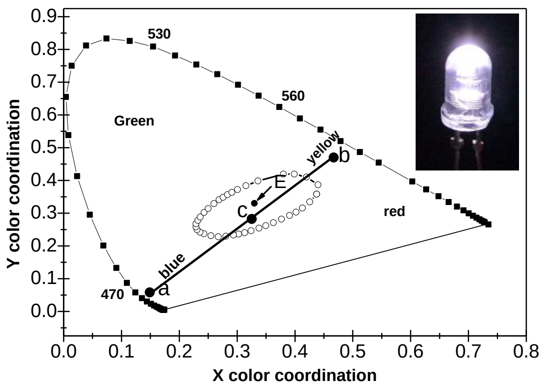


*Fig. 2. Coordinates of the blue LED (a), yellow LED (b), and white LED (c) under 20 mA plotted in the CIE 1931 chromaticity diagram. Inset: the photograph of the white LED under 20 mA current excitation.*

Emission spectra of the WLED at different current ($I$ = 10, 20, 30, 40 mA) were measured, which are depicted in Fig. 3. The applied voltage was approximately 3.5 V. The coordinates of spectra were calculated and plotted in Fig. 4. It can be seen from Fig. 3, the intensities of about 450-nm emissions increase with the increasing of current from 10 to 40 mA. The higher the current is, the stronger the blue emission is. In addition, the peak wavelengths and the full-width at half-maximum (FWHM) of the blue emission band are 449, 449, 449, 450 nm, and 48, 49, 51, 51 nm, respectively. The slight red shift and the widened FWHM may make coordinate of the WLED have a small change. For the yellow emission band, the emission intensity increases with current increasing until a maximum intensity is reached when the current is 30 mA, i.e. the emission intensity of the yellow phosphor “saturates” at a current over 30 mA. This indicates that this yellow phosphor cannot be used with high current. On the other hand, the degree of the increase in yellow emission is smaller than that of the increase in blue emissions with the current increasing, which results in the CIE chromaticity coordinate moving toward blue light point, as shown in Fig. 4.

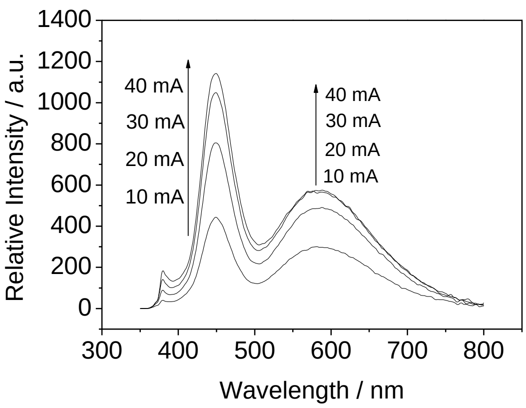


*Fig. 3. Emission spectra of the WLED under DC 10, 20, 30 and 40 mA.*

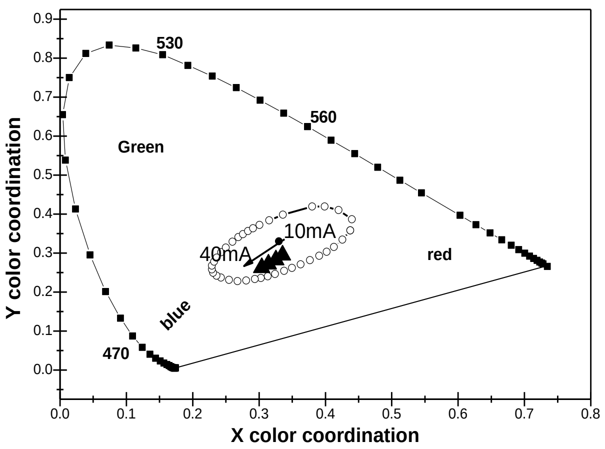


*Fig. 4. Coordinates of the WLED (▲) under 10, 20, 30 and 40 mA plotted in the CIE 1931 chromaticity diagram.*

The CIE parameters of the WLED under various currents are listed in Table 1. With current increasing, the color temperature $T_c$ increase from 5334 K to 8608 K and color rendering index $R_a$ decrease from 90.3 to 86.9. This can be explained that the emission intensity of the yellow phosphor "saturate" at a current about 30 mA and then with high current the ratio of yellow emission to blue emission in the WLED decreases. The $R_a$ of the WLED (90.3) is much more than that of the conventional YAG: Ce-based WLED (around 80) at a current about 20 mA. This is due to much red light emission of the yellow phosphor $Ba_2Mg(PO_4)_2$: $Eu^{2+}$ than YAG: Ce, as it is observed that PL peak of the yellow phosphor shifts from ~540 (YAG: Ce) [17] to 588 nm ($Ba_2Mg(PO_4)_2$: $Eu^{2+}$).

*Table 1. CIE parameters calculated from the spectra of the WLED under various currents.*

| Current (mA) | Coordinate | $T_c$ (K) | $R_a$ |
|---|---|---|---|
| 10 | (0.3355, 0.2947) | 5334 | 90.1 |
| 20 | (0.3253, 0.2822) | 5998 | 90.3 |
| 30 | (0.3142, 0.2713) | 7172 | 88.5 |
| 40 | (0.3041, 0.2622) | 8608 | 86.9 |

## 4. Conclusion

In summary, a two-band WLED was fabricated by precoating the blue phosphor $LiSrPO_4$: $Eu^{2+}$ and the yellow phosphor $Ba_2Mg(PO_4)_2$: $Eu^{2+}$ on an NUV InGaN LED chip. It was found that the increasing current from 10 to 40 mA results in higher color temperature $T_c$ and lower color rendering index $R_a$. When operated at a DC 20 mA, the CIE chromaticity coordinate, the color temperature $T_c$ and the color rendering index $R_a$ of the WLED are (0.3253, 0.2822), 5998 K and 90.3, respectively. These results indicate that this WLED has higher $R_a$ than the conventional YAG: Ce-based WLED.


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