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The Yellow Ring Measurement for the Phosphor-converted White LED

Ching-Ching Yang\(^a\)*, Chun-Li Chang\(^a\), Kuo-Cheng Huang\(^b\) and Tai-Shan Liao\(^b\)

\(^a\)Associate Researcher, Instrument Technology Research Center, NARL, 20, R&D Rd. VI, Hsinchu Science Park, Hsinchu 300, Taiwan
\(^b\)Division Director, Instrument Technology Research Center, NARL, 20, R&D Rd. VI, Hsinchu Science Park, Hsinchu 300, Taiwan

Abstract

Since Nichia Corporation developed YAG-based phosphor successfully, which had provided the best performance of conversion efficiency, the phosphor-converted white LED is already regarded as the major manufacturing process for white light generation. In general, the principle of white light generation is that a blue chip emits yellowish green lights by passing through phosphor layer and then yellowish green lights mix part of blue lights to yield white lights. However, the consistency of the blue chip and the homogeneity of the phosphor layer are key factors to affect the quality of white LED. Due to the limitations of current LED package, bracket or phosphor, the lightspot of a white LED projection has the common features that yellow lights surround the periphery of white lights. This phenomenon is so-called “yellow ring”. The study aims to identify the scope of yellow ring by the RGB proportion of lightspot. In addition, we create an analysis model of yellow ring to evaluate the degree of yellow ring in white light LED. From the experiment result, the yellow ring will appear when blue light decreases over 15%, and disappear in case the intensity of white light drop down to 10~15%.

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1. Introduction

Rise in 1960’s, LED light sources have the advantages of small size, low power, low light attenuation and long life. Coupled with the increasing flux efficiency and environmental protection and energy saving demands recently, LED light sources have gradually replaced the traditional lamps to be the indispensable lighting source of new generation. However, in response to the market demand, like the backlight of color cell phone screen and panel, the...
flash of digital camera and commercial lighting, the white LEDs make an unexpected appearance and own highest annual product-values than any other type LED in recent years.

The white light seen by human eyes is the mixture of at least two kind of monochromatic light, such as the combination of two-wavelength light (blue and yellow) or three-wavelength light (blue, green and red) [1]. In general, the LED emits a narrow wavelength monochromatic light and currently there are only blue, green, yellow and red LEDs available in the market. Due to the demand of white light sources increasing, the manufacturers apply many artificial methods to yield the light, for example, two complementary colors LEDs, three primary colors LEDs, three color phosphors excited by ultraviolet LED and the yellow fluorescent powder excited by blue LED (BLY Method) [2]. In these technologies to generate white light, the BLY Method is the most popular option for manufacturers, because of simple structure, low cost and high technical maturity. Furthermore, the related products have attracted much attention in the lighting market.

In order to generate the ideal white light, the high-brightness blue LEDs (460 – 490 nm) will be the initial light source and it will be packaged in transparent colloid, epoxy or silicone, mixed with yellow fluorescent powder. When the blue LED emits the blue light, one part of blue light will induce the yellow fluorescent powder to generate the yellowish green light, and the other part of blue light will travel through the fluorescent powder layer and mix with the yellowish green light to yield the white light [3]. Due to the limitations of current LED packaging, bracket or phosphor, the lightspot of white LED has a common feature that yellow lights surround the periphery of white lights. This phenomenon is so-called “yellow-ring” (YR). In practice, there are two approaches to reduce the YR phenomenon. The first one is to add the secondary optical component to cover the LED chip, say a reflector or TIR lens [4-6], which can remove the YR phenomenon but also decrease the flux efficiency of LED. The other one is to uniform the yellow lights by the discontinuous refractive element (Fresnel lens) [7], and all lights generated by white LED will be collected and the color of white LED lightspot will be homogenized. However, this approach may result in a decrease of color temperature, and the color rendering of white LED cannot meet the strictly requirements of lighting market.

The LEDs manufacturers inspect the projected lightspot by human visual perception to evaluate the optical quality of white LEDs. The result is usually not qualified enough to satisfy the customers that require the high color rendering of white LEDs. Therefore, how to create a standard measurement and define the extent of YR phenomenon is an urgent lesson. In the simulation, we take the white LED made by the BLY method as the experimental object and the lightspot of LED as the observation target. The study aims to identify the scope of YR by the RGB proportion of lightspot and create a YR model to evaluate the degree of YR in white light LED.

2. Analysis and Modeling of Yellow Ring

The YR phenomenon of phosphor-converted white LEDs is the commonly problem; it comes from the inhomogeneous phosphor layer sealed on the blue chip. In general, the YR will appear if the rays travel through side surfaces of LEDs, which piles up the more phosphor material [8], shown in Fig. 1.

![Fig. 1 The schematic diagram of the white light generated from the phosphor-converted white LED](image)

Based on the Benzoid-Brücke effect [9], the wavelengths of visible light sensed by human eyes will change while the light intensity increasing (refer to Eqn. 1), but in fact it has no change. That is, the feeling degree of the human eyes is about proportional to the color and light intensity. In addition, the white lights can be generated by mixing red, green and blue lights. The colour of LED lightspot will get closer to yellow when the proportion of blue lights
decreases (see Fig.1). In the study, we suppose the YR phenomenon is about proportional to light intensity, so the YR index (YRI) can be expressed as Eqn. (2).

\[ YRI = f(Y, I) \]  
\[ f(Y, I) = Y_0 \times I_0 \]

where 

\[ Y_0 = 1 - \frac{B}{255}, \quad I_0 = \frac{R + G + B}{3}; \quad R, G, B = 0 \sim 255 \]

The YRI is expressed as a percentage, and the values of Y and I vary from 0 to 255.

For the simulation and analysis of YR phenomenon, we develop a diagram which axis X and Y indicate the values of blue light and light intensity, respectively. Based on the YRI distribution, we can draw the proportional contour lines in Fig. 2. From Figure 2, the YR will appear in higher YRI areas and be difficult to identify in lower YRI areas and darker zones.

Based on the principles of luminosity function [10], the yellow-green light (555 nm) is the most sensitively for human vision in the day. However, the peak of visual sensitivity will change to the blue-green light (505 nm) in the dark environment (Purkinje shift) [11-12]. As shown in Fig. 2, the YRI diagram can be divided into three zones, I, II and III. The zone I is the area which the YR below 10, zone II is the area which the YR between 10 and 40, and the other area is zone III. The zone I, II and III present the slight, medium and deep YR, respectively. In general, every YRI has its corresponding coordinates in the diagram, so we can determine the degree of YR from its coordinates.

Fig. 2 The YRI diagram with the contour curves

We assume that the RGB value of YRI is a Gaussian distribution[13], so the R, G and B curves can be expressed as shown in Fig. 3a, respectively, and then the lightspot can be rebuild as shown in Fig. 3b. From human visual feeling, the point S (blue light decreases 15 %) and E (light intensity drops about 10 \sim 15 %) can be thought of the starting and ending points of YR (Fig. 3b). Therefore, the size of YR can be also demonstrated clearly in Fig. 3.

3. Experiment and Result Discussion

We set up a lightspot imaging system (LIS) for the YR measuring of LED, and the LIS comprises LED circuit board and bracket, neutral density filter, color camera, power controller and imaging processing system, shown in Fig. 4. The LED sample is 1 watt white LED (Cree XR-E Q5). The sensor of color camera has 1,388 \times 1,038 pixels (8.95 \times 6.7 mm) and its pixel size is 6.45 um. During the experiment, the colors of camera need to be calibrated by the white balance process and the central axis of the lens is required to coincide with the optical axis of LED. The
tunable current of LED can make the lightspot is brighter or darker. In general, the current of LED is 300mA and the forward voltage of LED is 3.2V.

Fig. 3a The R, G and B curves map (bottom), 3b The simulated lightspot (up)

Fig. 4 Schematic of lightspot imaging system (LIS)
When the power is turned on, the lights of LED travel through the neutral density filter and the lightspot diagram can be obtained by color camera. The YRI and light intensity of the real lightspot can be determined from the Eqn. 2, shown in Fig. 5. The YRI will increase gradually from the intensity 100% to 75%, and decrease from the intensity 75% to 10%. When the light intensity is around 75%, the YRI can reach a maximum value 76%. Moreover, when the light intensity is about 92% (YRI = 55%), the YR of lightspot can be recognized readily by human eyes. In the contrast, the YR will be too blurred to be indentified when the light intensity drops to 10 – 15%.

Different from the real lightspot, the light intensity of simulated lightspot (Fig. 3b) decrease to about 50% at the beginning of YR. The sensor of LIS has reached the color saturation status, so the light intensity of real lightspot is brighter in its center. Therefore, the YR of real lightspot can be seen obviously for human eyes. In practice, the intensity difference in the simulated lightspot can be corrected by adjusting the power of LED for testing in different environment. From the real lightspot diagram, the YR mapping line can be illustrated in Fig.6. If the quality control standard of YR is the QC line A, the quality of real lightspot is qualified; but the quality is bad if YR quality of LED is controlled on the standard of QC line B.
4. Conclusion

This study presents the modeling of YR phenomenon for the phosphor-converted white LEDs. Based on the YRI model, the YR phenomenon of LED can be defined in quantitative term. The size and degree of YR can be determined from the point S and E and YR zones. For the requirements of customers, the simulated lightspot can be rebuilt by their quality control standard. Therefore, the LED manufacturers can follow the YRI model to create their own YR quality control standard and make the YR testing process of LED more efficient and reliable.

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References