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Research on adjustable correlated color temperature COB-LED light source based on flip chips and screen printing technology

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Abstract

Using the characteristic of flip light emitting diode (LED) chips without front-side welding wires, before applying fluorescent glue throughout the luminous surface, a part of the chips are directionally and quantitatively coated fluorescent glue by screen printing process, a chip on board (COB) white LED light source is developed with adjustable correlated color temperature (CCT). A part of the blue LED chips in the light source excites the fluorescent glue to produce a warm white light (CCT = 2631K), and the other part produces cool white light (CCT = 6181K). When changing the driving current ratio of the two parts of the chips, the CCT of COB LED light source can be continuously adjusted between warm and cool white light. According to the measured data, the relationship between the CCT and the driving current ratio of the two parts is obtained by fitting. Within the adjustable range of the CCT (2631 K to 6181 K), the color rendering index (CRI) is about 90. The minimum is 89.3 and the maximum is 93.1. While achieving adjustable CCT and high CRI, the LED light source has a luminous flux of 1938.76 lm on a circular surface with a diameter of 11 mm. The overall luminous efficiency is close to 100 lm/W.

1. Introduction

White LED is the current mainstream green lighting source which has the advantages of energy saving, eco-friendly, long lifetime and high reliability, etc[1]. With the improvement of living standards, in different environments, human beings have different requirements for the photometric or colorimetric parameters of the light source such as luminance, CCT, CRI, etc[2,3]. Intelligent lighting can adjust and control the color of the lighting source at different occasions or time periods. Thus people can live and work in a better physiological and psychological state[4,5]. COB LED lighting source with adjustable CCT is the core component of intelligent lighting to achieve color temperature regulation.

At present, there are several ways to realize the adjustable CCT of LED in a single package: (1) A variety of monochrome chips are mixed and packaged. This structure uses many kinds of LED chips [6], and the packaging process is complex, the circuit control is difficult and the cost is high. (2) The CCT of LED can be adjusted by adding red chips into the packaging structure[7]. The CRI of this light source varies greatly at different CCT, and the CRI is very low at a low CCT. (3) The color temperature can be adjusted by using chip scale package(CSP) device and chip hybrid package. Compared with the pure COB LED light source, it has a lower optical power density per unit area, larger volume and higher cost[8].

Aiming at the deficiencies of the above technical schemes, we designed and made a CCT-adjustable LED light source which adopts the flip COB packaging and the screen printing process to print phosphors in a part of the LED chips directionally. By changing the driving current ratio of the two-part chips[9], making the LED light source can be adjusted the CCT within 2631 K to 6181 K continuously. Finally, we tested the Photometric and colorimetric parameters of the LED light source. The results show that the CRI is around 90 in the adjustable interval of CCT, while the minimum is 89.3, the maximum is 93.1.

2. Design And Making Of The Cob-led Light Source

2.1 Design of the COB-LED light source

The electrode layer of the flip LED chip is at the bottom of the chip, the photons generated in the active layer are emitted through the substrate. The luminous surface is not blocked by the electrode layer, so the light extraction efficiency is relatively higher. For light sources made with flip chips, the distance between electrode layer and the active layer from the substrate is short and the electrode area is large. The heat generated in the active layer can be easily transferred to the substrate, so the light source has a high heat dissipation capability[10]. There are no gold wires connected to the front of the flip chip, and the sapphire substrate itself has a high hardness, so the front of the chip can withstand a lot of pressure, which provides the possibility for directional coating of phosphors by screen printing technology.[11–13].

Screen printing belongs to orifice printing. By designing the size of the screen mesh opening and scraper hardness, controlling reasonable process parameters such as mesh spacing, printing speed, scraper pressure, snap-off distance, etc., it allows the coating amount of printing glue to be controlled precisely. The high thixotropy of jelly glue with two-component silicone has a good vertical flow resistance and little transverse flow. After it is coated on the chip, it forms a convex camber on the surface under the action of surface tension. The radius of curvature is related to the diameter and viscosity of the glue. When the screen printing process is used to directionally print some chips with fluorescent glue, we take advantage of the characteristics of high thixotropy of jelly glue with two-component silicone, and the fluorescent glue is made by mixing jelly glue with a variety of phosphors in a specific ratio.

The LED light source we designed is a high-conductivity aluminum substrate with a square side length of 16 mm and a round luminous surface diameter of 11 mm. It is composed of 24 GaN-based blue LED chips of 0.66 mm * 0.76 mm. Among them, 12 blue LED chips are connected in series, and then two-series chips are connected in parallel again. The arrangement of the series-wound and parallel chips is shown in Fig. 1. The two-group chips excite different phosphors respectively, by changing the driving current of the two-group chips, the CCT of the light source can be continuously changed between the CCT of the two-group chips driven separately. Under the premise of ensuring series-parallel connection, we design the arrangement of the chip on the substrate reasonably, so that the two-group chips are evenly arranged on the luminous surface.

Nitrogen oxide blue-green powder with emission wavelength of 490nm, YAG yellow-green powder with emission wavelength of 525nm and 537nm, and nitride red powder with emission wavelength of 639nm and 655nm were selected, and the emission spectrum curves were shown in Fig. 2. The main function of YAG yellow-green phosphor is to be excited by blue chips to produce white light, blue-green phosphor can supplement the lack of green-blue light component in the white light spectrum[14]. The red phosphors with different emission wavelengths can enrich the red light band in the spectrum, which can also effectively improve the CRI of the light source, especially the R9 that people are particularly concerned about[15].

2.2 Making of the COB-LED light source

The structure of the COB-LED light source is shown in Fig. 3, the bottom is a high conductivity aluminum substrate. Tin paste is used to bond chips on the substrate with a designed circuit and the position. After the tin paste is solidified by the process of reflow soldering, the chips are firmly bonded to the substrate. In addition, after completing the die bonding, the first kind of fluorescent glue is printed directionally on a part of the chips by screen printing process, and this part of the chips (hereinafter referred to as group A chip) excites the first kind of fluorescent glue to produce warm white light. The whole luminous area is enclosed in a circle (technically called the enclosure dam), and the second kind of fluorescent glue is coated in the enclosure dam ring. The other part of the unprinted fluorescent glue chips (hereinafter referred to as group B chip) mainly excites the second kind of fluorescent glue to produce cool white light.

When using blue chips to make warm white LED, the luminous efficiency of YAG yellow-green phosphor using 537nm is higher than that of 525nm phosphor, and the color rendering index(CRI) of the light source can be improved by using nitride red phosphor with wavelengths of 639nm and 655nm simultaneously. Therefore, in the preparation of fluorescent glue for screen printing(the first kind of fluorescent glue), which uses jelly glue with 537nm yellow-green phosphor, 639nm and 655nm red phosphor, the mass ratio of various materials is 1:0.656:0.054:0.049.

When blue chips are used to make cool white LED, higher luminous efficiency can be obtained by using 525nm yellow-green phosphor, higher CRI by using 655nm red phosphor than 639nm red phosphor. At the same time, the cyan phosphor of 490nm is used to make up for the lack of cyan band in the white light spectrum. The encapsulating glue of two-component silicone is used with blue-green phosphor with an emission wavelength of 490nm, yellow-green phosphor of 525nm and red phosphor of 655nm to prepare fluorescent glue for cool white light coating (the second kind of fluorescent glue), the various materials are 1:0.159:0.012:0.004 by mass ratio. This fluorescent glue has good leveling property. After curing, it is flat, smooth and bubble-free, which is conducive to the coating of the dispensing process.

3. Typical Parameters Of Cob-led Light Source

3.1 Typical values of COB-LED light source

The Photometric and colorimetric performance parameters of the light source are tested by lighting up the two-group chips of A and B. Table 1 shows the CCT, chromaticity coordinate, luminous flux, luminous efficacy and CRI of the light source when five groups of different typical driving currents are taken.

We can see from Table 1, when the ratio of group A chip driving current (I_A) / group B chip driving current (I_B) decreases, the proportion of cool white light in mixed white light increases gradually, the CCT of light source increases, and the chromaticity coordinate decreases accordingly. Meanwhile, with the increase of the cool white component in the light component, the luminous efficiency also increases slightly. This is mainly due to the fact that the luminous efficiency (106.3lm/W) of the cool white LED made by the same chip is higher than that of the warm white LED (92.1lm/W). When we change the driving current of the two-group chips of A and B, the CRI of the light source will also change accordingly. When I_A or I_B is equal to 0, the CRI of the light source is 89.3 and 89.5 respectively. Both are slightly less than 90. If I_A and I_B are not equal to 0, the CRI is over 90, and the highest is over 93.

When the two-group chips are taking different combinations of driving current, the spectra of WLED is shown in Fig. 4. The black line is the spectrum when the driving current of group A is 300 mA and that of group B is 0. At this time, the LED light source produces warm white light with the CCT of 2675K, which we can see from Fig. 4 that the blue light in the short-wave part is much lower in intensity than the red light in the long-wave part, which is only about 1/5 of the long-wave part. When the I_A/I_B decreases, the cool white component in the light source increases, and the ratio of the blue light part to the long-wave part is also gradually increasing. At the same time, the proportion of yellow-green light in the 500-550nm band in the spectrum is also gradually increasing.

When I_A/I_B is equal to 1, the spectrum is blue line in Fig. 4. The CCT of LED light source is 4093 K, and the intensity ratio of the short-wavelength blue light to the long-wave part of the red light is 1. When the driving current of group A is 0 and that of group B is 300 mA, the green line is shown in Fig. 4. LED light source produces cool white light and the CCT is 6123 K, the intensity of the yellow-green light component has exceeded that of the red light component. The peak of photoluminescent part of the fluorescent in the spectrum is converted to 525nm yellow-green light excited by the YAG fluorescent, and the ratio of blue light to yellow-green light intensity is 2.

3.2 Performance of COB-LED light source

3.2.1 Colorimetric parameters of COB-LED light source vs single group of chips

When group A or group B chip is lit up individually, the relationship between the CCT of the light source and the driving current is measured, the driving current is 30, 60, 90, 120, 150, 180, 210, 240, 270 and 300 mA respectively. Figure 5 shows the experimental data and the fitting lines. Black data are the CCT of group A chip changing with driving current, and the blue data are the CCT of group B chip changing with driving current. From this we can see that the change of color temperature is approximately linear. It can be seen from Fig. 5 that with the change of driving current, the CCT of the two-group chips of A and B have corresponding red fitting lines.

When a single group of chips is lighted up, the CCT of LED light source changes little with the driving current, and the CCT of group A chip increases from 2631 K to 2675 K, a difference of 44 K. The CCT of group B chip increases from 6130 K to 6181 K, a difference of 51 K. Accordingly, when a single group of chips is lit, the chromaticity coordinate of the light source changes very little with the driving current. When the group A chip is lit, the change of CCT with driving current can be fitted with the function equation as

$$CCT(I_A) = 0.16 I_A + 2621.33 \quad (1)$$

When the group B chip is lit, the change of CCT with driving current can be fitted with the function equation as

$$CCT(I_B) = -0.22 I_B + 6190.5 \quad (2)$$

3.2.2 Colorimetric parameters of COB-LED light source vs two-group chips

3.2.2.1 Correlated color temperature(CCT) of COB-LED light source

Lighting two sets of chips simultaneously. By changing the ratio of the driving currents of the two-group chips, the CCT of the LED light source can be continuously adjusted in a wide range, and the chromaticity coordinate can vary greatly. [9]. During the test, the driving current of group A chip is constant at 300 mA, the driving current range of group B is 30 to 300 mA, one group of data is measured every 30 mA interval, then the ratio of I_B/I_A changes in the range of 0.1 to 1. Similarly, when the driving current of group B chip is constant at 300 mA, the driving current range of group A chip is 30 to 300 mA, one group of data is measured every 30 mA interval, then the ratio of I_A/I_B changes in the range of 0.1 to 1.

In Fig. 6, the abscissa is the driving current ratio of two-group chips, and the ordinate is the CCT of the light source. Data in which the CCT of the light source varies with I_A/I_B are red. The data that the CCT of the light source varies with I_B/I_A are black. When the I_A/I_B increases from 0.1 to 1, the CCT gradually changes from 5691 K to 4110 K. The reason for this phenomenon is the increase of warm white component in light components. When the I_B/I_A increases from 0.1 to 1, the CCT gradually changes from 2976 K to 4110 K. This is due to the increase of cool white component in mixed white light components, the CCT gradually changes from warm white to neutral white. When considering the case of lighting up a group of chips individually, the CCT of the light source is continuously adjusted within the range of 2631 K to 6181 K. The red line in Fig. 6 is the fitting line of CCT with I_A/I_B, when the driving current of group A chip is changed and the driving current of group B chip remains unchanged. When the I_A/I_B increases, the CCT of LED light source decreases, which is a monotonic decreasing function of I_A/I_B, and the change of CCT with I_A/I_B can be fitted with the function equation as

$$CCT\left(\frac{I_A}{I_B}\right) = 1908.3\left(\frac{I_A}{I_B}\right)^2 - 3745.6\frac{I_A}{I_B} + 5973.4 \tag{3}$$

The black line in fig. 6 is the fitting line of CCT with I_B/I_A, when the driving current of group A chip is constant and the driving current of group B chip is changed. When the I_B/I_A increases, the CCT of LED light source increases, which is a monotonic increasing function of I_B/I_A, and the change of CCT with I_B/I_A can be fitted with the function equation as

$$CCT\left(\frac{I_B}{I_A}\right) = -765.53\left(\frac{I_B}{I_A}\right)^2 + 2706.4\frac{I_B}{I_A} + 2789.3 \tag{4}$$

The ratio between the changing CCT of the light source and the driving currents of the two-group chips can be visually seen in the form of Fig. 6. However, the I_A/I_B and I_B/I_A are used respectively in the whole interval of change. The CCT is inconvenient to adjust and control in practical applications. Based on the analysis of the data, taking $\ln(I_A/I_B)$ as the abscissa, the variation line of CCT with $\ln(I_A/I_B)$ is drawn, as showed in Fig. 7.

It can be seen from the distribution of experimental data, there is an approximate linear relationship between CCT and ln (I_A/I_B), which can be fitted with the following equation as

$$CCT\left(\ln\left(\frac{I_A}{I_B}\right)\right) = -626.03\ln\left(\frac{I_A}{I_B}\right) + 4144.96 \tag{5}$$

The relationship between CCT and driving current can be directly obtained by linear fitting. In the case that the requirement of CCT is not strict extremely, you can use the above Eq. (5). When we need to control the CCT accurately, in order to eliminate the error caused by linear fitting and the chromatic difference of different light sources, we can actually measure the CCT of different driving current ratio to form an adjustment calibration line of CCT. When measuring the calibrated line, the range and changing magnitude of the driving current ratio can be flexibly selected according to the actual need. The CCT can be accurately controlled by using an intelligent system that can retrieve data to call the calibrated line directly.

3.2.2.2 Color rendering index(CRI) of the light source

The two-group chips are lighted up at the same time, by changing the driving current ratio between the two-group chips, the CCT of LED light source changes greatly. When the CCT of the LED light source can be adjusted in a wide range, the CRI at different CCT is tested. The CRI corresponding to LED light source at different CCT is shown in Fig. 8, in which the abscissa is the CCT and the ordinate is the color rendering index.

As showed in Fig. 8, when two-group chips are lighted up simultaneously, the CRI of the LED light source is kept above 90 in the adjustable range of the CCT. An interesting phenomenon is discovered here, when the warm white LED is lighted up individually, the CRI is 89.3; while the cool white LED is lighted up individually, the CRI is 89.5. When two-group chips are lighted up concurrently, the CRI of the light source is improved in different driving current ratios and the maximum is 93.2.

The physical mechanism that causes this phenomenon is that when warm white light is lighted up individually, three kinds of fluorescent whose main excitation peak wavelengths are 537nm, 639nm and 655nm; When cool white light is lighted up individually, three kinds of fluorescent whose main excitation peak wavelengths are 490nm, 525nm and 655nm. At this time, the spectral compositions of white LED are not vivid enough, so the color rendering index of LED light source is slightly low. When two-group chips are lighted up at the same time, five kinds of fluorescent with excitation peak wavelengths of 490nm, 525nm, 537nm, 639nm and 655nm are excited simultaneously and efficiently. So the spectrum of the LED contains components of the emission spectrum about five kinds of fluorescent, the entire spectrum is richer and smoother, the CRI is significantly improved.

4. Conclusion And Future Work

By using flip LED chips and screen printing process, we have designed and made a kind of COB-LED light source with adjustable CCT and high CRI. The two-group chips in the light source can excite fluorescent of different kinds and ratios, which produce white light with two different CCT. When the driving current ratio of two-group chips changes, the CCT can continuously change between the above two CCT values. By changing the kinds, ratios and dosage of fluorescent in the two kinds of fluorescent glue, the adjustable range of CCT is different and can be obtained. This enables the CCT of COB-LED light source to vary in any range. The CCT of 24 W LED allochroic light source can be adjusted continuously in the range of 2631K to 6181K. In the range of CCT adjustment, the CRI are high all the time. The minimum is 89.3 and the maximum is 93.1.

The luminous efficiency of the light source made in this paper is about 100 lm/W. When the same chips and the same types of fluorescent are used, its luminous efficiency of the light source is slightly lower(about 10%) than that of the LED light source with the same structure and single CCT. This is the price must be paid in order to realize the adjustable CCT so that the fluorescent can not be fully excited. For the scenes of applications with high requirements for luminous efficiency, we can do this by reducing the driving current density of the chips or selecting blue LED chips with higher brightness.

Declarations

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Disclosures

The co-authors declare that they have no known competing financial interests or personal relationships, and that existing financial interests or personal relationships do not affect the work to be reported in this paper.

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Tables

Table 1: The Photometric and colorimetric performance parameters of the light source when five groups of different typical driving currents are taken

I		CCT/ K	CIE		Luminous flux/ lm	Luminous efficiency/ (lm/W)	CRI
I_A/ mA	I_B/ mA		X	Y			
300	0	2675	0.4687	0.4228	986.09	92.1	89.3
300	150	3641	0.3963	0.3827	1489.04	94.4	93.1
300	300	4093	0.3740	0.3640	1938.76	95.4	92.5
150	300	4583	0.3568	0.3537	1582.15	100.2	93
0	300	6123	0.3193	0.3346	1136.93	106.3	89.5

Figures

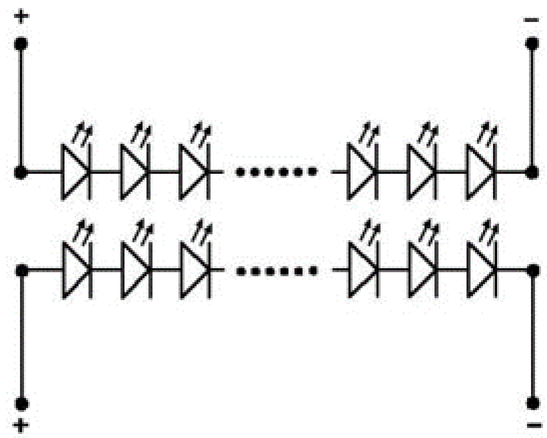

Figure 1

The circuit diagram of the chips for connection

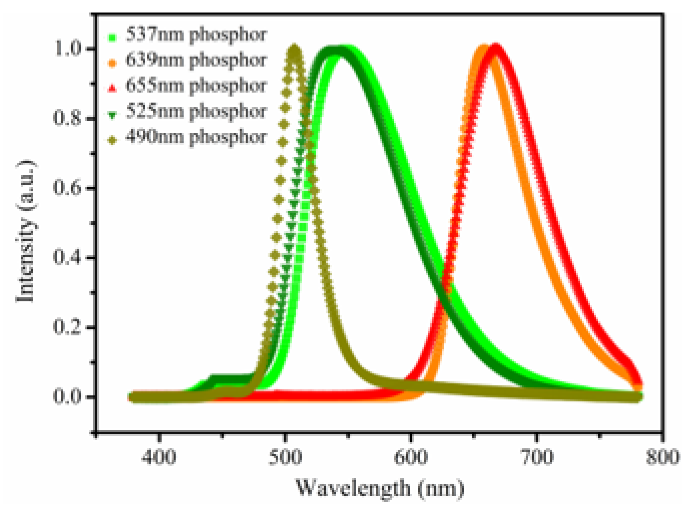

Figure 2

Relative spectra curves of the five phosphors

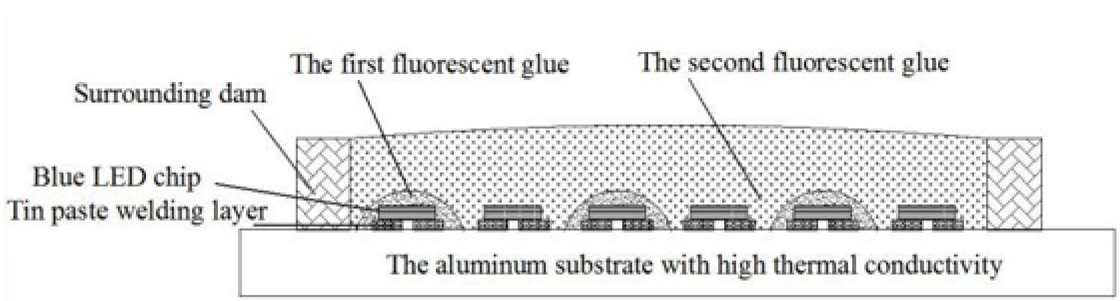

Figure 3

Schematic diagram of the COB-LED light source

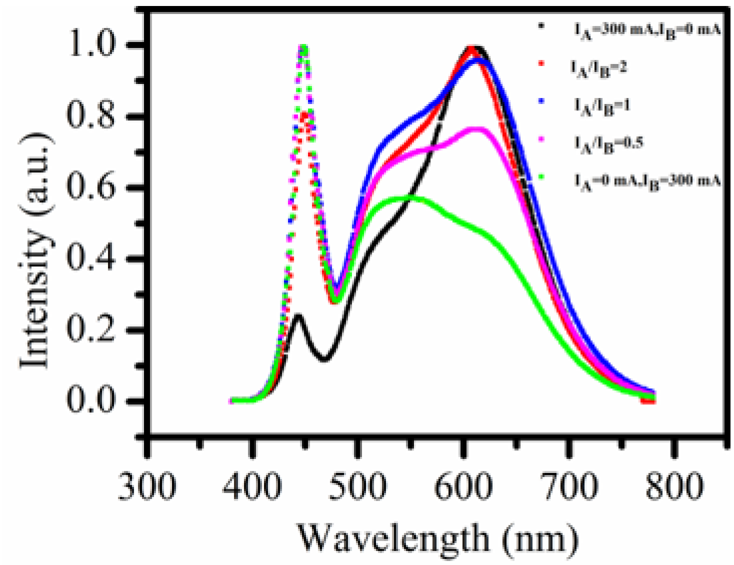

Figure 4

Spectra of LED with different driving currents

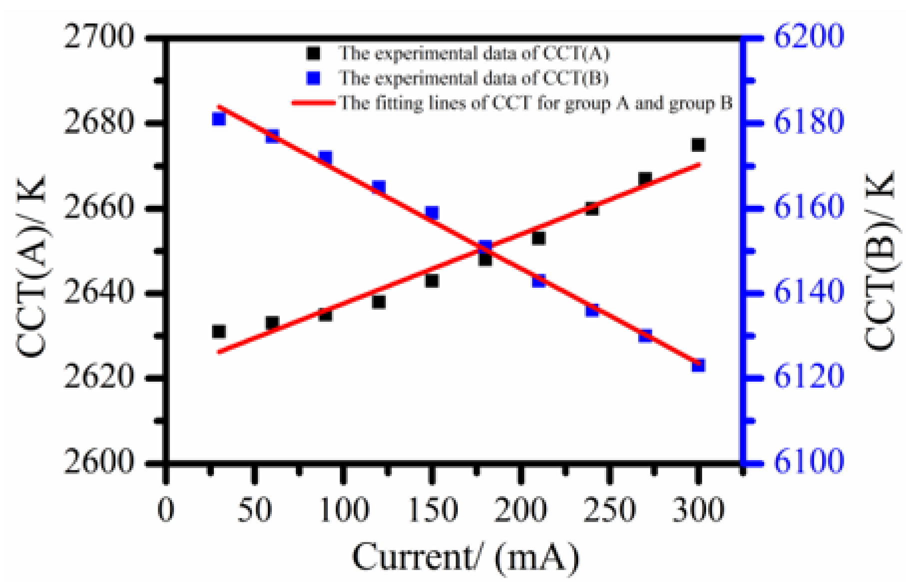

Figure 5

Variation of the CCT with different driving current when lighting up a single group of chips

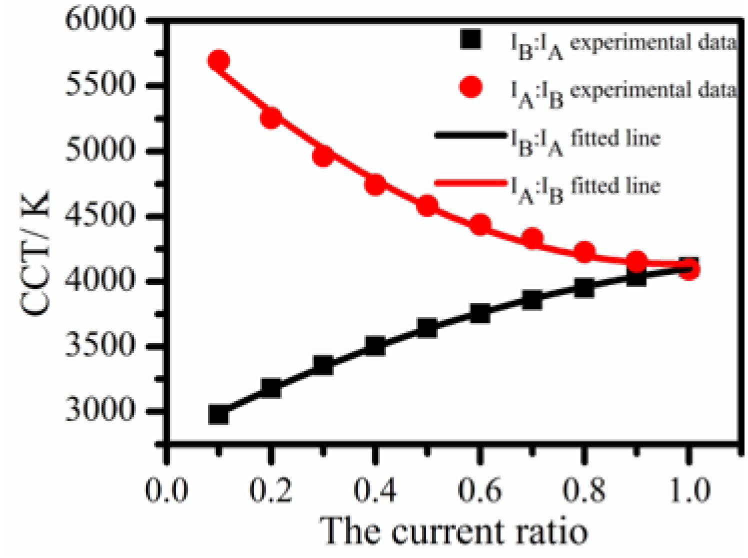

Figure 6

The relationship of CCT with the driving current ratio of two-group chips

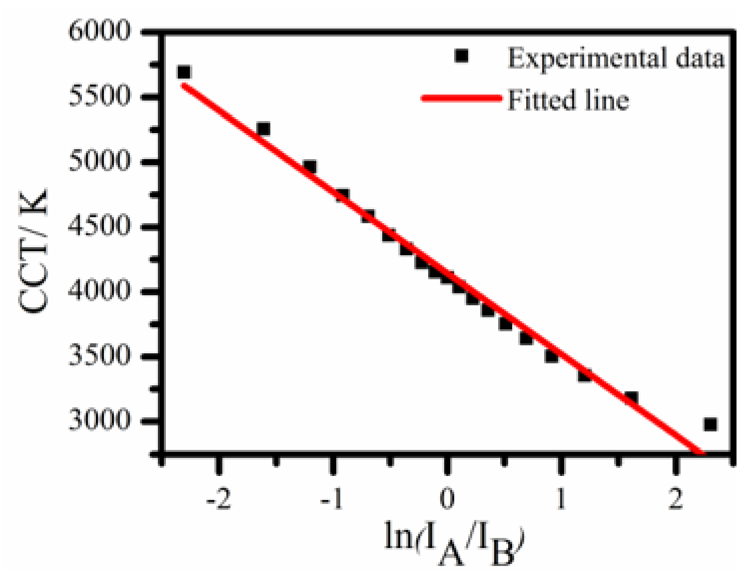

Figure 7

The correlation between of the CCT and ln(IA/IB)

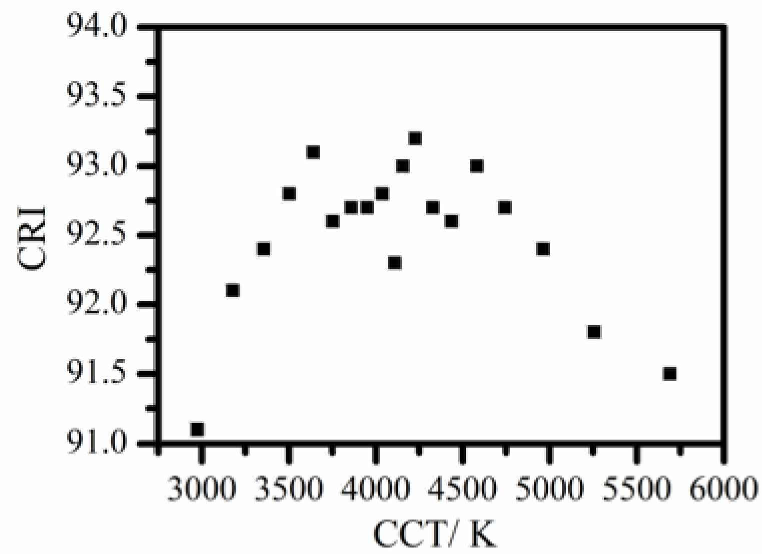

Figure 8

The color rendering index of LED light source at different CCT