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# Fabrication of a Large LCD Backlight Unit with Red, Green, and Blue LED Lamps

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## Abstract

A backlight unit for a 42-inch LCD TV was manufactured with red, green, and blue LED lamps. The luminous and light extraction efficiencies of the LED lamps were increased by improving their light reflection structures and thermal properties. The blue, green, and red LED lamps showed different luminous efficiencies as a function of the input current. Compared to the conventional red LED lamp, however, the developed red LED lamp showed very high luminous efficiency in a low drive current. Taking these luminous efficiencies into account, the fabricated backlight unit showed high energy efficiency, low power consumption, and a wide color gamut.

**Keywords**: Light-emitting diode, red, green, and blue LED lamps, luminous efficiency, LCD backlight unit

## 1. Introduction

It is well known that the cold cathode fluorescent lamp (CCFL), which is currently the most widely used lamp for the LCD backlight, is a reliable light source with high brightness, high energy efficiency, and low-cost mass production. It causes environmental pollution, however, as it contains mercury. Nowadays, the LED lamp is widely used in diverse electronic equipment and electrical scoreboards due to its outstanding electric characteristics. A white-light LED lamp was recently made, using near-ultraviolet LED and RGB phosphor [1, 2]. The LED lamp was developed rapidly because it does not cause environmental pollution, but the use of the LED lamp poses problems as well. First, the cost of an entire system for installing heat emission tools is quite high. Second, it has high power consumption because of its low energy efficiency. Lastly, its color gamut is not wide when the white-light source is made from blue light and yellow phosphor [3]. To address these problems, the possibility of improving the LED lamp's quantum efficiency by increasing its light extraction efficiency [4, 5] and by operating it at a low-current density was looked into in this study, and a new lead frame technology was developed to improve its thermal capability.

High-quality white light can be generated by mixing three primary colors. Thronton showed that mixing discrete emission bands with peak wavelengths near 450, 540, and 610 nm will result in a high-quality white-light source [6]. Chhajed reported contour plots of luminous radiation efficacy and of the color-rendering index (CRI) of a trichromatic source with a color temperature of 6500 K, and showed the relation between the CRI index and energy efficiency on one hand and the three LED wavelengths on the other [7]. Trichromatic white-light sources can be generated in two different ways: by complementarily combining three phosphors with a monolithic LED lamp, and by using GaN-based blue and green LED lamps as well as an AlGaInP red LED lamp with complementary wavelengths, respectively. White-light sources with red, green, and blue LED lamps were designed, and they showed a high-quality color gamut [8]. An optically and thermally improved LED lamp was made using a developed lead frame, which drastically reduces the thermal resistance, and the luminous efficiency and optical properties of the LED lamp were investigated within the range of a low drive current [9].

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In this study, a 42-inch backlight unit (BLU) for an LCD TV with blue, green, and red LED lamps was manufactured by reducing the thermal resistance and improving the light reflection structures of the LED lamps, and the luminous properties of the BLU were investigated. The optical properties of the red LED lamp and its driving current density were reported for the first time, and it showed the same luminous properties as the GaN-based blue and green LED lamps within the range of a very small current density. An efficient BLU was made by optimizing the chip size and drive current in terms of energy efficiency and cost.

## 2. Experiment

A LED BLU was designed to have a diagonal length of 42 inches and a 10,000 nit brightness. Its luminous characteristics were defined by [10], as follows:

$$\text{Luminance} = \frac{\varepsilon K P}{\pi S}, \tag{1}$$

where $\varepsilon$ is the system efficiency, $K$ the luminous efficiency of LED [lm/W], P the electrical power of LED [W], and $S$ the screen size [$m^2$].

Since the system efficiency was 1.38, the required total flux became 11,000 1m. The target color coordinate indices of the panel were also designed to be (0.28, 0.29). Then the flux ratio of the red, green, and blue LED lamps was 3.4:11.4:1.0, and their total fluxes were 2,400, 7,999, and 702 1m, respectively. The peak wavelengths of the red, green, and blue LED were 635, 524, and 452 nm, respectively. As the number of each color lamp was 1,008, the fluxes of the red, green, and blue LED lamps were 2.38, 7.94, and 0.70 1m, respectively. The color gamut was 117% NTSC, and the fluxes of the red, green, and blue LED lamps were designed to enhance the lamps' energy efficiency and to reduce their cost.

A conventional BLU consisting of a diffuser plate, a diffuser sheet, and a prism sheet was used. The red, green, and blue LED lamps installed at the bottom chassis were arranged in triangular shapes that had the same distances between them. The optical thickness between the bottom chassis and the diffuser plate was only 20 mm, and the optical thickness of the conventional BLU was 30 mm. An aluminum substrate was used for the bottom chassis.

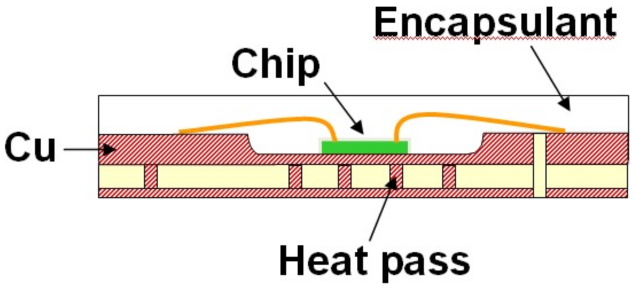

**Fig. 1.** Schematic diagram of the developed LED lamp.

The size of the LED lamp was 3.5×2.8 mm, and its thickness was 350 micron. In earlier experiments, the heat resistance of the LED lamp was reported to be 61.6 K/W [4], which includes the thermal resistance of the test plate. Thus, the thermal resistance of the LED lamp was actually only 20.1 K/W. The cross-sectional view of the LED lamp that was used as a BLU light source is shown in Fig. 1. A light guide structure with a 200 micron depth was formed on a Cu plate using the etching process. This light guide structure uses most of the surface area under the encapsulant for light reflection, whereas a conventional LED package has a deep light reflection structure. Compared to the light reflection structure of a conventional LED package, this developed light guide structure helps the light generated from the LED lamp come out of the package much efficiently. After chip mounting and molding, the epoxy is removed to form heat transfer paths, and a low-thermal-resistance LED lamp is manufactured. The luminous fluxes were measured using a CDS 500 Lab sphere with a 10-inch-diameter integration sphere.

## 3. Results and Discussion

Fig. 2, 3, and 4 show both luminous efficiency and luminous flux as functions of the input current for the red, green, and blue LED lamps, respectively, with various chip sizes. RLE320 and RLF320 in Fig. 2 represent the luminous efficiency and luminous flux, respectively, of a 320×320-μm red chip. The luminous flux increased along with the current and chip size. On the other hand, the luminous efficiency decreased as the current increased. The luminous efficiency was becoming saturated in the region of the high drive current.

For the red, green, and blue LED lamps, however, the luminous efficiency sharply increased as the input current

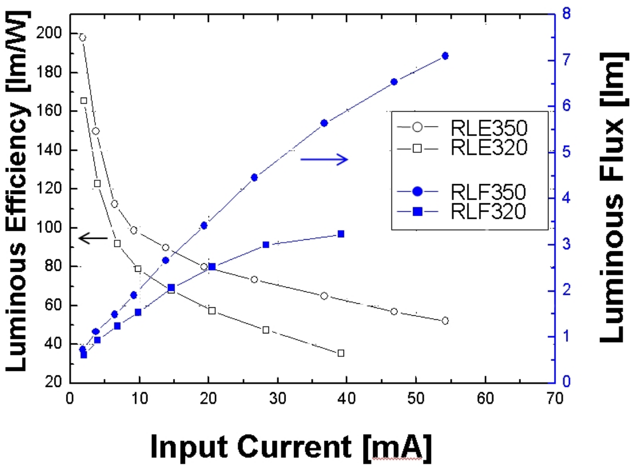

**Fig. 2.** Luminous fluxes and efficiencies of the red LED lamps as a function of the input current.

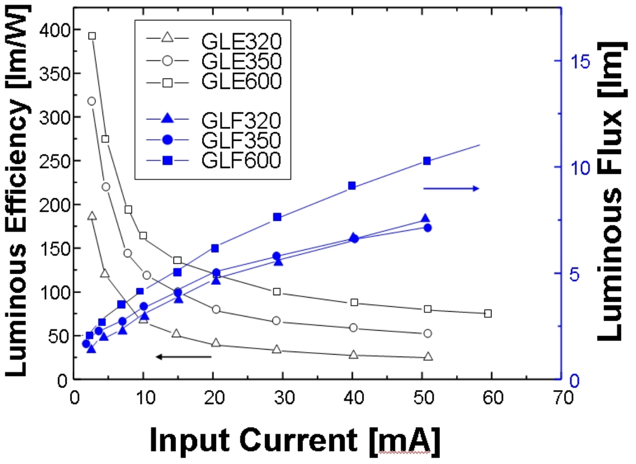

**Fig. 3.** Luminous fluxes and efficiencies of the green LED lamps as a function of the input current.

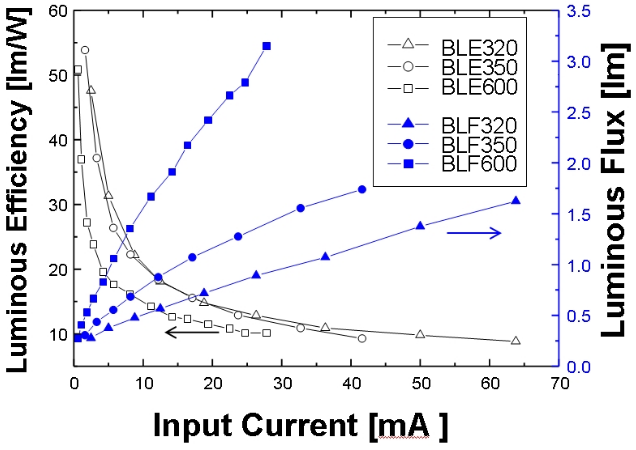

**Fig. 4.** Luminous fluxes and efficiencies of the blue LED lamps as a function of the input current

decreased. The sharply increasing luminous efficiency of the red LED lamp in the very small current region was observed for the first time. It showed the same luminous properties as the GaN-based blue and green LED lamps within the range of a very small current density. Although these findings are not clearly understood, they are believed to be closely related with the quantum efficiency and heat generation in LED lamps [11].

The numbers of the red, green, and blue LED lamps were chosen considering the color mixing and optical thickness of the BLU. Low-current-density operation requires the use of a large chip, which is more expensive than the small one. To optimize the chip size, the optimum operating current of a small chip was chosen for the blue LED lamp. A large green chip was chosen, however, for operation in a low-current-density region because it requires high luminous intensity and efficiency. For comparison, the blue LED lamp was operated in a high-current density region since it is not very sensitive to a current density above 20 A/cm$^2$. For the red LED lamp, RLE350 was chosen rather than RLE320 because the luminous efficiency of RLE350 is much higher than that of RLE320.

The optical specification of the LED lamp that was used in this research is shown in Table 1. To increase the luminous efficiency, low-current-density operation was performed by increasing the chip area and the number of LED lamps. The green LED lamp with a patterned substrate enhanced the luminous efficiency by 5% [12] and was operated at an extremely low current density. The chip sizes of the red, green, and blue LED lamps that were used for the BLU were 350×350, 600×600, and 320×320 μm, respectively. The applied voltages of the red, green, and blue LED lamps were 2.1, 3.2, and 3.1 V, respectively. The red, green, and blue LED lamps were operated with the current of 20, 30, and 20 mA, respectively. The current density of the green LED lamp at 30 mA was much lower compared to those of the red and blue LED lamps because its chip area was about four times larger. The luminous efficiency of 55 lm/W for the BLU made with the red, green, and blue LED lamps is shown in Table 1.

The characteristics of the manufactured BLU for a 42-inch LCD TV are shown in Table 2, and these are compared with those of the conventional BLU. It is shown that the developed LCD BLU has higher brightness and a wider color gamut compared to the conventional BLU. The power consumption of the BLU was determined to be 201 W at the brightness of 10,000 nit and the color gamut of 117% NTSC.

**Table 1.** Optical Characteristics of a 42-inch LED BLU with red, green, and blue LED lamps.

| | Red LED | Green LED | Blue LED | Total |
|---|---|---|---|---|
| Luminous flux (lm) | 2,400 | 7,999 | 702 | 11,101 |
| Number of LED lamps | 1,008 | 1,008 | 1,008 | 3,024 |
| Power consumption (W) | 42 | 97 | 62 | 201 |

**Table 2.** Comparison of the Characteristics of the developed and conventional BLUs.

| Characteristics | Developed BLU | Conventional BLU |
|---|---|---|
| Luminance (nit) | 10,000 | 6,000 |
| Color gamut | 117% NTSC | 92% NTSC |
| Power consumption (W) | 201 | 210 |

## 4. Conclusions

A 42-inch LED BLU was fabricated using red, green, and blue LED lamps with a low thermal resistance of 20.1K/W and with improved light reflection structures. The chip sizes were determined considering the efficiency, optimum operating current density, and manufacturing cost. The BLU has a color gamut of 117% NTSC, a luminous efficiency of 55 lm/W, and a power consumption of 201 W at the brightness of 10,000 nit.

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