Development of a Very Small LED Lamp with a Low-Thermal-Resistance Lead Frame for an LCD Backlight Unit

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Abstract

In this study, a very small LED packaging lead frame with a low thermal resistance was developed. The cost of the package process was reduced by the use of many small LED lamps, which increased the light emission efficiency. Compared to the large lead frame lamp, however, the optical property of the small LED packaging lead frame lamp was not sufficiently improved because its reflection structure was changed and its reflection area was reduced. The luminous efficiency of the LED lamp reaches 58 lm/W at the current density of 0.16 A/cm^2. Using the LED lamps, 46-inch LCD BLU was manufactured. The BLU-made LED lamps have a low power consumption of 146 W and have a slim (10-mm-thick) BLU, keeping good uniformity in terms of brightness, and maintaining good thermal properties.

Keywords: light-emitting diode (LED), LCD backlight unit, lead frame, LED chip

1. Introduction

CCFL (cold cathode fluorescent lamp) is currently the most widely used LCD backlight source. CCFL has high brightness, high energy efficiency, low cost, and a long life. It causes environmental pollution, however, due to the mercury in its lamp. As for the xenon gas and electroluminescence lamps, they are still not sufficiently efficient and reliable to allow mass production even if they do not cause environmental pollution. As the LED lamp does not cause environmental pollution, and because it has a long life, reliability, and excellent electrical and optical properties, it has been applied to cellular phones, a variety of electronic products, cars, traffic signals, and display products. Recently, a silicon molding material that shows high light transmission within the range of visible-light wavelength and nitride phosphor, and which has highly efficient red-light emission, was developed [1]. The LED lamp, however, is not very much applied to LCD BLUs (backlight units) even if it has many advantages, for the following reasons. First, its material cost for high-current operation to achieve sufficient brightness is quite high. Second, it has high power consumption due to its low optical efficiency, and it has life and reliability problems. To address its cost-related limitation, it is necessary to reduce its process cost by increasing the size of the wafer, to improve its high-cost process (e.g., scribing and separation), and to reduce its material cost by improving its packaging process [2].

The improvement of the LED lamp's energy efficiency was also studied to improve its internal quantum efficiency by changing the structure of its quantum well or the optical properties of thin film, and to improve its light extraction efficiency using a patterned substrate technology [3, 4]. Low-current operation [5] and a new lead frame technology for reducing the frame's thermal resistance were also actively studied to improve the LED lamp's energy efficiency [2].

In this study, the light extraction efficiency of the LED lamp was improved with low-current operation and the use of a new lead frame technology, by reducing the frame's thermal resistance and improving the lamp's reflection structure. The lamp's light extraction efficiency was improved by reducing the chip size and increasing the surface area to prevent the reabsorption of light. To reduce the manufacturing cost, a very small packaging technology was developed, and a 46-inch LED BLU with LED lamps was manufactured.

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2. Experiment

A very small LED lamp with a low-thermal-resistance lead frame was developed in this study. Fig. 1 shows three different types of LED lamps. Fig. 1(a) shows a conventional 3.5 × 2.8-mm SMD-(surface-mounted device)-type LED, Fig. 1(b) a conventional 1.6 × 0.8-mm SMD-type LED, and Fig. 1(c) the low-thermal-resistance 1.6 × 0.8-mm and 0.25-mm-thick SMD-type LED that was developed in this study. As shown in Fig. 1(a), the thermal resistance of the conventional 3.5 × 2.8-mm SMD-type LED was high because its heat path is long. That is, the heat generated from the LED chip is transferred to the mother board, as shown by the arrow. The very small SMD-type LED lamp in Fig. 1(c) also has a very low thermal resistance because its heat path is short and the heat conduction of the copper therein is very high. The manufacturing cost of the developed LED lamp shown in Fig.1(c) is low because its lead frame is the small PCB (printed circuit board) type.

In this study, a 46-inch LCD BLU with very small LED lamps was manufactured. The optical components of the BLU are a diffuser plate, diffuser sheet, prism sheet, and protection sheet. The BLU is only 10 mm thick, whereas the typical BLU is about 30 mm thick. LED lamps have been attached to the FR-4 sheet with special heat transfer structures. The luminous fluxes were measured using Labsphere's CDS 5000, whose light integration sphere has a 10-inch diameter.

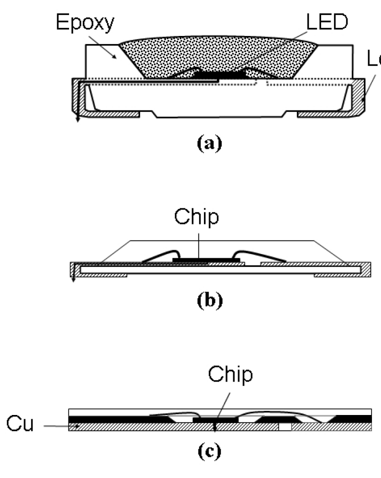

Fig. 1. LED package and lead frame structures. (a) 3.5 × 2.8-mm conventional-SMD-type LED lamp. (b) 1.6 × 0.8-mm conventional-SMD-type LED lamp. (c) The developed 1.6 × 0.8/3.8 × 0.8-mm and 0.25-mm-thick low-thermal-resistance SMD-type LED lamp.

3. Results and Discussion

Fig. 2 shows the luminous flux and efficiency of LED lamps as a function of the input current. It shows the luminous flux and efficiency of many large LED lamps installed in a large lead frame. The LED lamp shown in Fig. 1(c) has a well-developed lead frame that is large (3.8 × 0.8 mm) and is 0.25 mm thick. There are three types of chips, with different sizes: 0.6 × 0.6 mm (J size), 0.35 × 0.35 mm (A size), and 0.32 × 0.28 mm (C size).

The luminous efficiency increases exponentially in a low-current-density region as the current density decreases [6], but the luminous flux amount is not high for a small chip. As such, a higher current drive is necessary to obtain a sufficient luminous flux. As can be seen in Fig. 2, an increased luminous flux and greater efficiency can be obtained using three small chips with the same junction area at a constant current drive. The luminous flux of the A-sized chip increased by 33% (from 13.5 lm to 18 lm) compared to the two other A-sized LED lamps operated at the current of 20 mA, and one J-sized LED lamp is operated at the current of 60 mA. The packaging cost is high, however, because three lead frames must be used. Therefore, to reduce the packaging cost, the lead frame and lamp must be made smaller. In addition, an efficient light reflection structure and a low thermal resistance are necessary to improve the optical and thermal properties of the lamp.

Thermal resistance is defined as

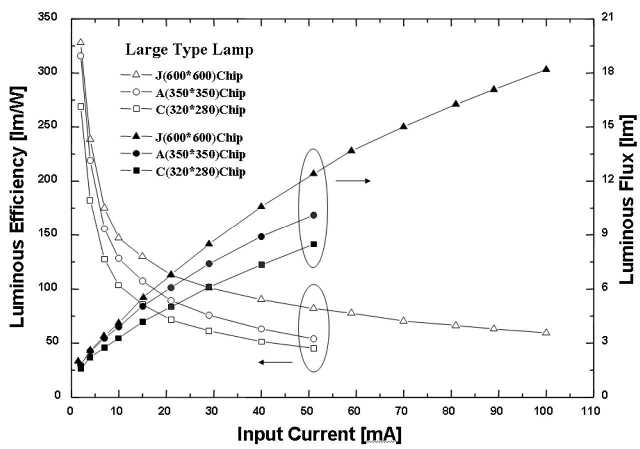

Fig. 2. Luminous flux and efficiency as a function of the input current for various chip sizes: 0.6 × 0.6 mm (J size), 0.35 × 0.35 mm (A size), and 0.32 × 0.28 mm (C size). The structure of the developed LED lamp is like that shown in Fig. 1(c) and is a 3.8 × 0.8-mm and 0.25-mm-thick low-thermal-resistance SMD type.

$$R_{th} = \frac{L}{kA}, \tag{1}$$

where k is the thermal conductivity, L the thickness, and A the area of the material. The thermal resistance is reduced when a higher-thermal-conductivity material is used. The thermal resistance is proportional to the thickness of the LED lamp and is inversely proportional to its area.

Table 1 shows the thermal characteristics of large and small LED lamps where a new lead frame was applied. The large LED lamp shows a lower thermal resistance compared to the conventional lamp, but the small LED lamp developed in this study shows a considerably high thermal resistance. The developed LED lamp is also capable of heat transfer through the copper sheet in the lead frame structure, which has a low thermal resistance. Moreover, compared to the large LED lamp, the small LED lamp has a small surface area, which increased the lamp's thermal resistance. The thickness of the sapphire and bonding paste for the bonding die on the high-thermal-resistance lead frame is constant, but the surface area was reduced. The thermal resistance of the lamp became 144.8ºC/W [2].

Fig. 3 shows the luminous flux and efficiency of the developed small LED lamp and the conventional small LED lamp. The developed small LED lamp has a low thermal resistance due to its improved lead frame, and the conventional small LED lamp has the structure shown in Fig. 1(b). The sizes of the chips are the same, and the phosphor for making white light is YAG (yttrium aluminum garnet). Its efficiency is saturated at around 100 mA and then decreases as the current density increases to above 100 mA since the conventional lead frame has a large thermal resistance. It was shown, however, that the luminous flux and efficiency of the developed LED lamp considerably increased and that its saturation point reaches the input current of 200 mA. The reason for this is that the thermal resistance of the developed LED lamp is low even if it is small because the heat generated from the LED chip is transferred efficiently by the copper material, which is thin and has high thermal conductivity.

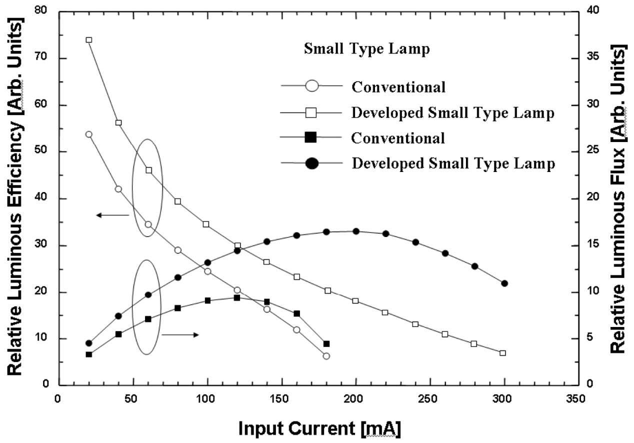

Fig. 3. Luminous flux and efficiency as a function of the input current for the conventional and developed small lead frames.

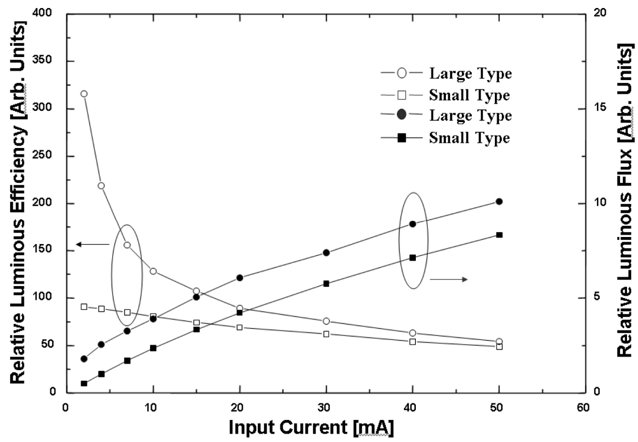

Fig. 4. The luminous flux and efficiency of LED lamps where large and small lead frames with LED chips were installed.

Fig. 4 compares the luminous flux and efficiency of LED lamps in which same-sized LED chips were installed, with large and small lead frames. In the large LED lamp, a small LED chip was installed in a large lead frame, whereas in the small LED lamp, a small LED chip was installed in a very small lead frame. The luminous efficiency of the large packaging increased considerably as the current density decreased, but that of the small packaging did not increase much as the current density decreases in a low-density cur-

Table 1. Thermal Characteristics of LED Lamps

LED lamp	I_d(mA)	I_m(mA)	V_f(V)	P(W)	R_{th}(K/W)	T_j(℃)
Conventional	60	3	3.220	0.192	80.125	40.384
Large type	100	3	3.140	1.314	61.6158	44.347
Small type	20	3	3.140	0.064	144.814	34.268

rent region. As such, the luminous efficiency of the very small LED lamp did not increase much. It is expected that its optical properties and thermal resistance will change with the variation of the size of its lead frame. As discussed earlier, the thermal resistance of the small lead frame increased. The light reflection of the large LED lamp has a hemispherical structure while that of the small LED lamp has a rectangular structure. Thus, the light extraction efficiency of the small LED lamp is low compared to the large LED lamp, and the reflection area of the top surface of the lead frame decreased in the small LED lamp. Due to the lamp's optical structure, the chip reabsorbs the reflected light more, which reduces the light extraction [9].

A 46-inch LCD BLU with the developed small lamps was manufactured in this study. Fig. 5 shows the luminous-intensity uniformity in various points of the BLU. The optical distance can be reduced when many very small LED lamps are used. The optical distance of the typical large lamp is about 30 mm while that of the very small lamp is only 10 mm. The brightness uniformity of the lamp can even be improved by about 2%.

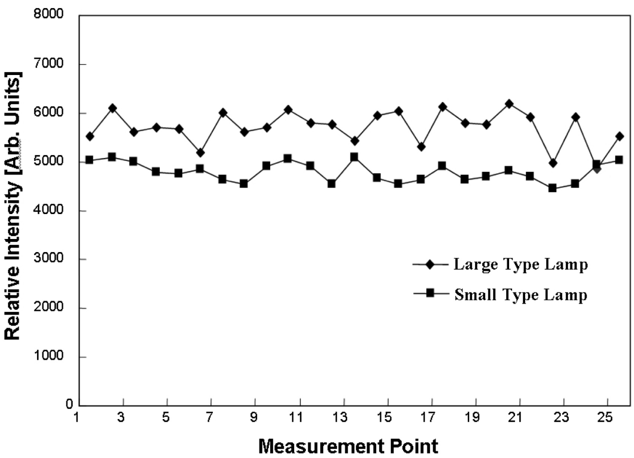

Fig. 5. Luminous-intensity uniformity in various points of a 46-inch LCD BLU.

Table 2. Characteristics of the 46-Inch LCD BLU with a Conventional LED Lamp, the Developed Large LED Lamp, and a Very Small LED Lamp

Content / Model	Conventional Lamp	Developed Large Type Lamp	Developed Small Type Lamp
BLU Brightness (nit)	7,000	9,000	7,680
CIE(x, y)	(0.2605, 0.2361)	(0.2779, 0.2575)	(0.2771, 0.2548)
Chip Size (μm)	500X500	600X600	350X350
LED Quantity (ea)	960	960	2,304
Thermal Resistivity (K/W)	80	62	145
Current Density (A/cm²)	0.24	0.16	0.16
LED Lum. Eff. (lm/W)	49.3	71.2	58.3
Power Consumption (W)	187 (60 mA)	170 (58mA)	146 (20mA)
Cost (%)	100	87	61

Table 2 shows the characteristics of the 46-inch LCD BLU with a conventional LED lamp, the developed large LED lamp, and the developed very small LED lamp. Compared to the conventional BLU, the developed BLU, which has a new lead frame and lamp, is operated at a lower current density and has improved luminous efficiency. The BLU with the developed small LED lamp, however, has low efficiency at a constant current density even though the cost of its packaging was reduced by about 40% because, as discussed earlier, the light reflection of its lead frame is poor. Its thermal resistance also increased because the area of the copper plate was reduced.

This research can address the problem of the high cost of the large LCD BLU by improving the luminous efficiency and energy efficiency of the LED lamp. Furthermore, it became possible to drive the LED at a lower current density and a lower temperature. The temperature of the plate of the LED lamp in the 46-inch LCD BLU was increased to 52ºC and was saturated after a 40-min drive. The reliability of the BLU and the life of the LED lamp were considerably improved.

4. Conclusions

A very small LED lamp with a low thermal resistance was developed in this study, and a 46-inch LCD BLU with the developed LED lamp was manufactured. The very small LED lamp has a 58 lm/W efficiency at the current density of 0.16 A/cm^2. The BLU that is made of the developed LED lamp is a slim one, with an optical distance of 10 mm and a low power consumption of 146 W, and with a high brightness uniformity and good thermal properties.

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