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Thermal characteristics and fabrication of silicon sub-mount based LED package

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ABSTRACT

In this paper, the cost of a light emitting diode (LED) package is lowered by using a silicon substrate as the base attached to the chip, in contrast to the conventional chip-on-board (COB) package. In addition we proposed an LED package with a new structure to promote reliability and lifespan by maximizing heat dissipation from the chip. We designed an LED package combining the advantages of COB based on conventional metal printed circuit board (PCB) and the merits of a silicon sub-mount as a substrate. When an input current 500–1000 mA was applied, the fabricated LED exhibited the light output of approximately 112 lm/W at 29 W. We also measured and compared the thermal resistance of the sub-mount package and conventional COB package. The measured thermal resistance of the sub-mount package with a reflective film of Ag and the COB package were 0.625 K/W and 1.352 K/W, respectively.

1. Introduction

The demand for high-output light emitting diode (LED) packages has increased with growing demand for LED lighting and diversified fields of application. Increasing the package light output has the advantage of enhancing light conversion efficiency [1–3]. At the same time, energy other than light, which is mostly released as heat, now accounts for 75–85% of the total energy applied. As detailed in numerous, recent studies on LED light output, this means that the visible light conversion efficiency of incandescent light bulbs has been exceeded. By securing the highest visible light energy conversion efficiency, LED lighting is expected to be widely utilized in the lighting markets of the near future. However, the greatest disadvantage of the LED is that 75–85% of the total energy applied is still expelled as heat. Thus, for further advancement, the first obstacle to overcome is heat transfer [4–6].

The structure of conventional LED lighting has seven complex thermal nodes, including the LED package thermal node and the metal printed circuit board (PCB) thermal node. Heat transfer generated from the chip during LED operation is difficult for this structure. Due to the complex manufacturing process of conventional LED modules and the structurally complex thermal node, in order to improve the heat dissipation characteristics, chip-on-board (COB) packages are being developed [7–11]. Many research studies have been done on the thermal characteristics of the high-power multi-chip LED packages [8,9]. The thermal mode analysis is used to optimize the thermal management with optimal locations and chip sizes for multi-chip package by Lai et al. [11]. Lee et al. have reported the low temperature co-fired ceramic chip-on-board (LTCC-COB) package with improved thermal characteristics without an insulation layer between the LED chip and metal base [10]. However, metal core PCBs generally used for COB packages have an isolation layer of low thermal conductivity between the chip mounting surface and aluminum metal PCB, which interferes with the heat transfer from the chip to the outside during LED operation. So, while the COB package has fewer thermal nodes, the low thermal conductivity of the isolation layer of the metal PCB hinders the heat transfer produced from the chip. Consequently, this impacts on LED reliability and lifespan. The ceramic substrate was introduced as part of the research to replace the dielectric layer having a low thermal conductivity [7]. However, ceramic substrate is often applied in small-scale applications due to the high cost. To overcome the low thermal conductivity of the isolation layer problems, silicon substrate was introduced in this paper which has the advantages of outstanding thermal conductivity, improving throughput with wafer-level packaging (WLP) technology, and reducing package material cost (lower cost module than AlN sub-mount). The silicon-based LED sub-mount technology has been introduced for reference [12]. This research shows that silicon LED sub-mounts lead to better thermal dissipation performance than do Al_2O_3 ceramic sub-mounts, and reveal acceptable insulation performance and high temperature reliability for silicon sub-mounts.

In this paper, a silicon sub-mount based LED package is proposed which employs a different method compared to the conventional COB package. This new package uses a silicon substrate on the base attached to the chip to reduce cost and to maximize heat transfer from the chip in

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order to improve reliability and lifespan. The LED package was designed with a structure that incorporates the advantages of the PCB based COB and silicon sub-mount, using the base as the substrate. Comparative analysis was conducted for the light output according to the input current, thermal resistance of the sub-mount package with Ag and Al reflective films, and thermal resistance of the conventional COB package. The silicon sub-mount package, however, still has very limited benefits. At present, silicon substrate does not bear the high-voltage power easily, and the manufacturing process of the silicon sub-mount package remains complicated. In addition, the market is also not mature, and the cost is more expensive than a conventional COB package. However, the cost of the silicon sub-mount package is similar to the cost of the package using chip-on-metal (COM) directly to the substrate to Al [13]. The cost of the Al substrate including the COM package is reasonable, although, the cost becomes more expensive, though, when adopting a high-gloss reflector to improve efficiency. The manufacturing process of the silicon sub-mount package is not over complex in that only one more step is added to the process. Furthermore, the silicon sub-mount package will be smaller because the technology can be integrated directly in the driving circuit itself.

2. Fundamentals of thermal properties

Thermal resistance in high-output LED packages is a critical factor affecting its reliability. It hinders the flow of heat between bonding interfaces from high temperature to low temperature. Moreover, thermal resistance is directly related to the chip junction temperature which can determine the reliability and lifespan of the LED device. Since temperature increase due to incomplete radiation deforms constituent materials or deteriorates the sealant and reliability of the chip itself, research on reducing the thermal resistance of packages to lower the chip junction temperature has been ongoing.

Eqs. (1)–(3) show the formulation for the thermal resistance of the heat released from the chip junction to the ambient. In contrast to the general electronic device package, the total energy applied for the high output LED is converted partially to light energy and simultaneously to heat energy. Also, the power dissipated as heat is approximately 80% of the total, and in the case of the LED package, the thermal noise generated from this power has to be reflected in the system measurement for accurate light output performance. In other words, when measuring light output or light properties, it is necessary to simultaneously measure the light output and heat, because the heat released from the LED package changes the light characteristics. The power applied to the LED converted to light output (combined luminance) and heat (combined non-luminance) can be expressed through the following equation. Further detail modeling is described in [14].

$$R_{ja} = \frac{T_j - T_a}{P_H} \tag{1}$$

Here, R_{ja} refers to the thermal resistance from the device junction to a specific environment, and T_j refers to the junction temperature at normal state. T_a refers to the reference temperature up to the specific environment and P_H refers to the multiplication of current and voltage in the general device.

$$P_{heat} = P_{el} - P_{opt} \tag{2}$$

Here, P_{heat} refers to the generated quantity of heat (W), P_{el} refers to the applied power (W), and P_{opt} refers to the light output. The optical properties of the LED are sensitive to temperature, so thermoelectric elements are used for the integrating sphere for the light output measurement to fix the surrounding temperature of the package.

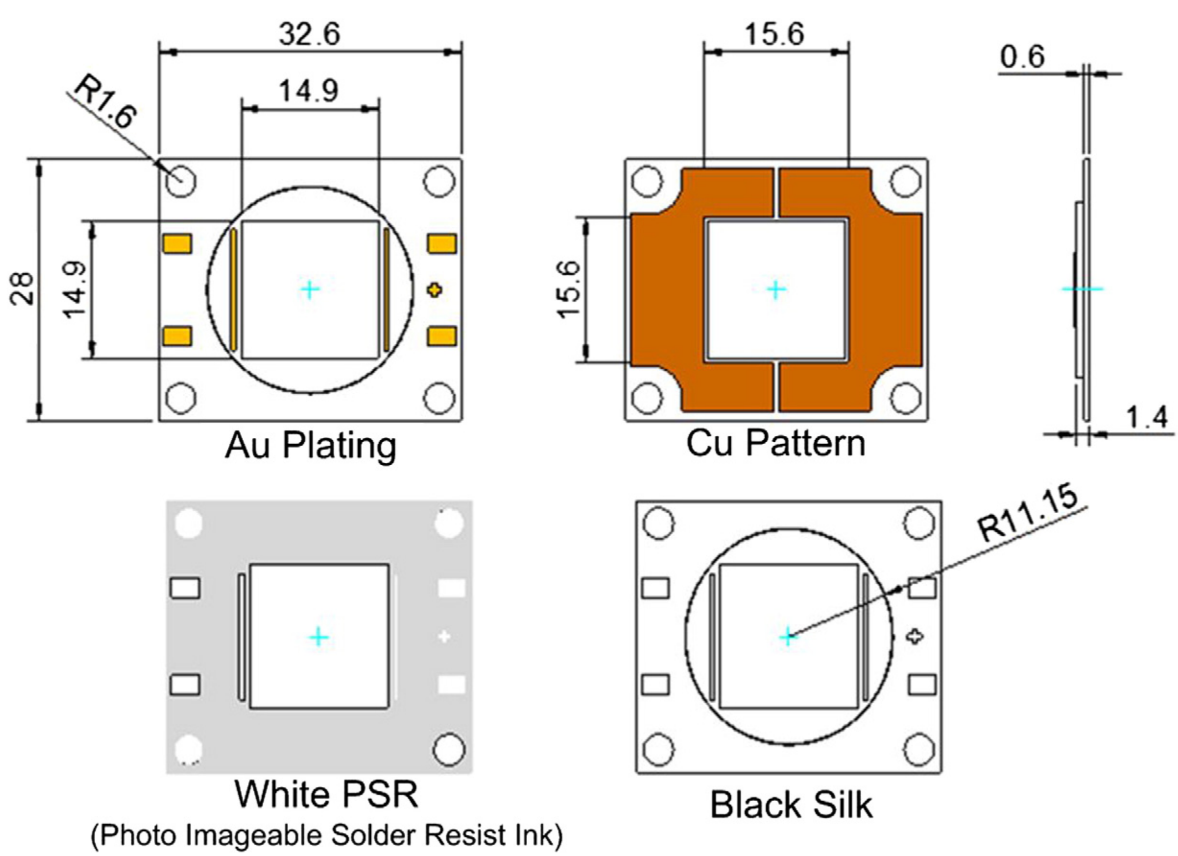

Fig. 1. Proposed LED package structure.