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Research Paper

Thermal distribution of multiple LED module

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HIGHLIGHTS

- A simplified thermal model was developed.
- Thermal FE analysis was performed on the LED module.
- MCPCB's thermal conductivity plays an important role in LED module's temperature.
- A mathematical formula was developed based on the simulation data.

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ABSTRACT

Light-emitting diode (LED) is an electronic device with high heat flux. The simulation and analysis of the heat dissipation play an important role in the improvement of performance and design of LED module. In this paper, a thermal model was developed using ANSYS software to simulate the temperature distribution of LED module. The effect of thermal conductivity of MCPCB (metal-core printed circuit board) substrate on the heat dissipation of LED module in the vertical direction and MCPCB substrate in the length and width direction was evaluated. A mathematical formula to describe the vertical temperature distribution of LED module was developed. The results showed that the maximum temperature of LED module and the temperature gradients near the outer edge of the contact surfaces between cooling blocks and MCPCB substrate decreased with the increase of thermal conductivity of MCPCB substrate.

1. Introduction

Compared with the traditional light sources, LEDs have multiple advantages, such as high efficiency, energy saving, good reliability and long service life [1–3]. Due to technological advances, a new record of luminous efficiency has reached 303 lm/W [4], which is beyond the reach of traditional light sources [5]. Therefore, LED light source is considered to be the most valuable energy in the 21st century [6] and is expected to replace the traditional light source gradually [7,8].

Currently, the single-chip LED module can no longer meet the demand of liquid crystal display back lighting source and general lighting because of its low total light output [9]. Possessing a higher forward current and employing multiple LEDs [10], the multi-chip chip-on-board LED modules [9,10] and multiple LED packages which were mounted on substrate modules [11–14] (Fig. 1) become the current development trend of the LED industry. However, these two types of LED modules generate more heat that causes a faster rise of junction temperature and consequently degrades the performance of LEDs, such as stability and luminous efficiency [15,16]. Therefore, reasonable thermal management for the high power LED module to make the junction temperature maintained within an allowable range and ensure its luminous quality and service life is the most important factor in the development of high power LED light source.

However, researches on thermal management for the widely used LED modules that employ multiple LED packages on substrate are quite rare currently, and most of the researches on the substrate were mainly focused on the effect of material properties [10,17,18], orientation [19] and thickness [10,12] on the heat dissipation performance of LED modules. Cheng et al. found that there was a larger thermal resistance on top of the MCPCB because of its low thermal conductivity [20]. Yung and his coworkers found that the inclination of 90° showed the lowest temperature and the highest overall light intensity of the LED when PCB inclined from 0 to 180° [13]. Weng pointed out that thicker copper plating can reduce the thermal resistance up to 25% [12]. Considering that MCPCB substrate was widely used in LED module and likely to lower the temperature of LED module via better design, the effect of thermal conductivity of

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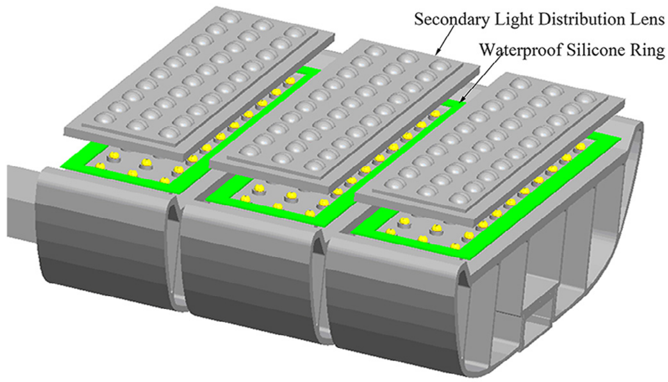

Fig. 1. Exploded view of a multiple LEDs lamp (omitting the front and rear end cover).

MCPCB substrate on the heat dissipation performance of LED module was studied using finite element analysis in this paper. Moreover, a mathematical formula to describe the vertical temperature distribution of the LED module was developed and validated.

2. Finite element model of the LED module

The majority of the heat generated by LED chips dissipates through the back of the chips to the heat sink by heat conduction, and then dissipates to the ambient environment by convection and radiation [21]. Moreover, the prototype of the high power LED module studied is complicated, and some of the components have a small effect on temperature distribution according to previous literature researches [21,22]. Furthermore, three identical modules are strung together to form the LED lamp (Fig. 1). Thus, referring to the one-dimensional heat transfer model developed in [8,23], a single module simplified model with the vertical thermal path was built, which consisted of the LED chip, die attach, cooling block, MCPCB substrate, thermal paste and heat sink from top to bottom, respectively, as shown in Fig. 2. The solder paste that was used to connect the cooling block and the MCPCB substrate was ignored due to its extremely thin thickness. The LEDs were arranged as a 3×10 array on MCPCB substrate, which is shown in Fig. 3. The three rows of LEDs were named as A, B and C, respectively, and each row of the LEDs was ordered from 1# to 10# from left to right. The central interval between two adjacent LEDs in two adjacent rows is 20 mm, and that in a row is 23 mm. The input power of each LED is 1 W.

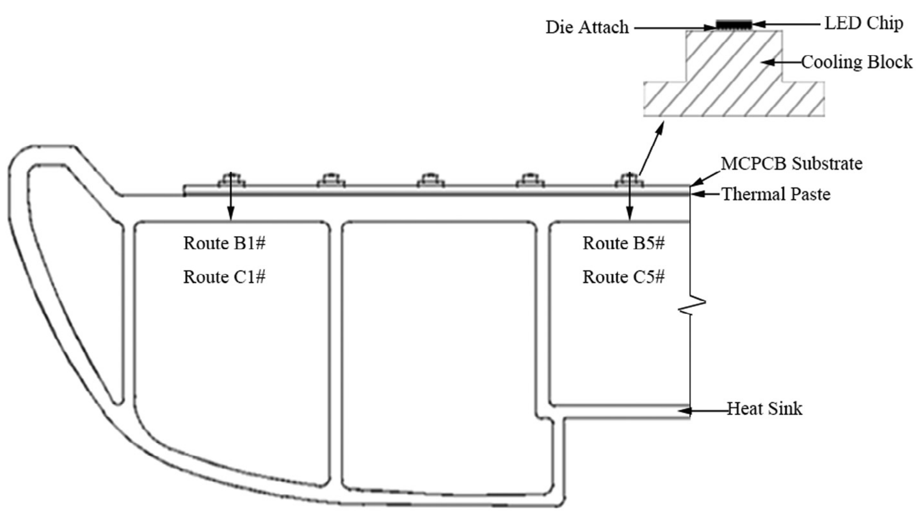

Fig. 2. Half cross-sectional view of the simplified LED module.

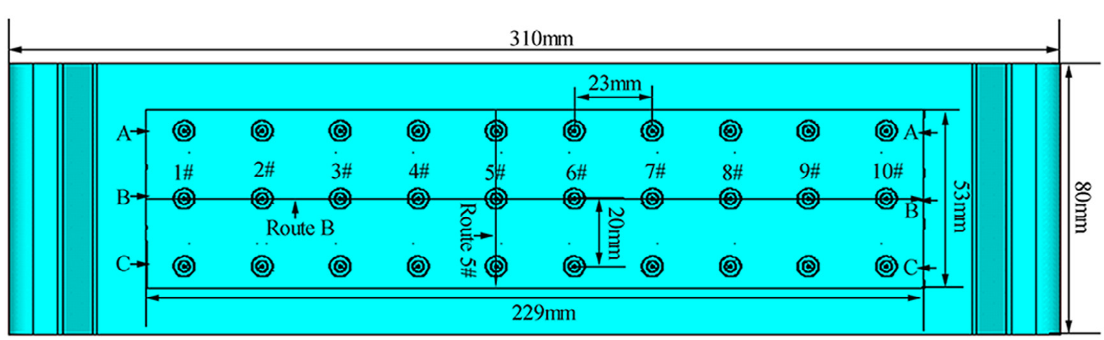

Fig. 3. Top view of the LED module.