



# Analyzing the structural designs and thermal performance of nonmetal lighting devices of LED bulbs



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## ARTICLE INFO

### Article history:

Received 31 August 2015

Received in revised form 6 January 2016

Accepted 23 March 2016

Available online 26 April 2016

### Keywords:

Composite material

Heat transfer coefficient

Holed design

Tunnel diversion

Inserted aluminum

## ABSTRACT

This study primarily investigated the heat dissipation problem in light-emitting diode (LED) lighting, designed and improved the structural designs of lighting devices of LED bulbs, and employed composite materials as the lighting structural material. This study applied holed designs, tunnel diversions, and inserted aluminum to various designs including finned and finless structures to improve the air convection effect during natural convection and reducing the LED temperature. Results showed that the highest temperature of the LED respectively dropped to 90.7 °C, 94.5 °C, and 79.0 °C when the finned structural designs of holed effects of the type of 8-mm diameter with 10 holes, tunnel diversion of the type C2 with the 8-mm external and the 6-mm internal diameters, and inserted aluminum of the type H2 of 40 mm insertion depth were applied. And analyzing the average heat convection coefficient ( $\bar{h}$ ) of the fins revealed that  $\bar{h}$  was as high as 4.74 W/m<sup>2</sup>-K with the holed design, whereas the tunnel diversion and the inserted aluminum designs yielded coefficients of 3.71 W/m<sup>2</sup>-K and 4.07 W/m<sup>2</sup>-K, respectively. Analysis showed a decrease in the LED maximum temperature of the finless lighting device from 99.8 °C to 82.1 °C when aluminum was inserted, enabling the transfer of heat energy accumulated inside the lighting structure, and lowering the overall temperature of the lighting system and extending its lifespan.

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## 1. Introduction

The rapid development of light-emitting diode (LED) is attributed to its ability to function without the need for warm-up time and high color rendering index. LED has more than 100,000 h lifespan, is highly reliable, small form factor, environmental friendliness and energy efficient, allowing it to command substantial influence in the traditional lighting market. Simply by combining the optical and electromechanical technologies available in Taiwan, various LED lighting instruments can be produced. In the past, used just as an indicator light, a single LED received a luminous current of between 5 mA and 30 mA, typically 20 mA, from a positive conduction current source. In contrast, nowadays the current passing through the high-power LED reaches 330 mA to 1 A [1–8]. However, because LED chips lean toward light, thin, and small exterior modeling, as well as multifunctional and high-efficiency internal designs, their structural arrangement yields a tighter assembly that elevates heat density, increasing the difficulty when

packaging them and further complicating problems involving heat dissipation. Studies have indicated that for each increase of 10 °C operating temperature in an electronic component, product reliability is reduced by 50%. When an LED is to be used as a light bulb, not only high brightness but also high power is a must. The power of high brightness LED is generally exceed 1 W at present and has the power density between 50 W/cm<sup>2</sup> and 100 W/cm<sup>2</sup> [9,10]. The high power density from LED will cause local temperatures rise and responsible for hot spots phenomenon. Then heat transfer and heat dissipation will appear as a problem. Heat dissipation techniques have become critical in developing LEDs. Therefore, the two-phase flow apparatus have been mostly used to deal with the hot spot problem caused by high power LED. Moreover, the overall effective thermal conductivity of the new heat spreader is forty to one hundred times greater than that of the copper substrate [11–14]. The heat-dissipating ability of an LED lighting instrument affects its stability and quality in that unsatisfactory heat dissipation negatively impacts the lifespan of the lighting instrument.

Lots of literatures can be found concerning the cooling of LED lamps, which are always operated under complex natural or forced convection [15–20]. The metallic or porcelain heat-dissipating

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materials were replaced with composite as lighting materials in the present study. The reason is that composite materials are economical, easy to process, and light; therefore, using this type of material in LED lights increases the competitiveness of LED lighting devices in the market. The heat-dissipating method of commercial high-intensity LED lighting in the market is primarily natural convection, which is affected by the quality of materials used and the design of the fins and body structures. However, to improve heat convection, this study implemented holed designs, tunnel diversion, and aluminum substrates in the finned and finless lighting instruments; multiple-holed interfaces facilitate more solid- and gas-contact surface areas for heat transfer and heat exchange. This study used commercial packaged software to predict the LED heat source, the lighting surface temperatures, the average heat convection coefficient of the fins, and the overall current speed of the lighting instrument. Using the simulation results, this study evaluated the LED lighting modules that dissipated heat most effectively. Developing heat-dissipating lighting modules with superior performance at low costs is critical for numerous manufacturers of LED lighting instruments.

## 2. Heat dissipation structural designs

### 2.1. Finned lighting devices

Fig. 1 shows the structural design of the finned lighting device used to illustrate a 3D graph, which was composed of composite materials and attached with 10 triangular fins in a ring array in this study. The finned lighting structure exhibiting an overall height of 50 mm and a width of 65 mm has a cylindrical center with a 30-mm diameter and 45-mm depth, which enables convenient wiring when assembling the LED lighting module. The finned lighting device included three types of designs, including the holed design, tunnel diversion, and inserted metal.

The first design type is the hole effect. Using the design concept of destroying the boundary layer of the lighting structure to improve heat dissipation reported that this concept can be achieved through natural convection from open holes, enabling improved heat convection on the surfaces of the fins and solving the problem of poor heat dissipation that occurs when composite materials are used. Through the open-hole heat-dissipation concept and simulation verification, this study aimed to provide a new heat dissipation model that effectively increases the heat-dissipating area, reduces wind resistance, increases air delivery, and enhances thermal conductivity, thereby improving the heat-

dissipating ability of the lighting device and reducing its overall mass. However, this holed design maybe has a question in practicality. The switching mode power supply and screw installed in the LED bulb structure have to pay attention particularly. In this study, holes of varying diameters were arranged differently on a finned light bulb. The size specification in Fig. 1(b) shows that the overall height of the instrument without the round top (5 mm) was 45 mm. The holes were arranged in rows at 5 mm from the top plate. After the optimal hole diameter between 1 mm and 9 mm was confirmed, the holes were then arranged in order, and the space for attaching the base and the lamp holder was reserved. Fig. 2 shows the concept of the holed design, displaying 10 holes in each row; each additional row provided 10 holes, yielding a total of 50 holes in five rows.

And the second design type is the tunnel diversion. In normal natural convection, smoothly eliminating heat energy from the LED device through the tunnel ventilation system must be considered to maintain the ideal heat transfer in the lighting device. In high-power heat conditions, waste heat is removed from the lighting device through tunnel diversion to minimize the damage to the lighting structure; an ideal ventilating design should enable natural air convection, transferring the heat in the lighting system flow to the external environment. This study investigated the use of tunnel diversion to increase the airflow in natural convection, thus improving the heat transfer effect of the finned lighting device, enabling the device to effectively dissipate heat. However, this phenomenon is frequently restricted by the effectiveness of the convection area. Fig. 3 shows the two tunnel diversion designs in this study. The interior of the cylinder in Type C1 was penetrated with conduits, which removed waste heat from the lighting structure as air passed through the conduit. Type C2, slightly similar to

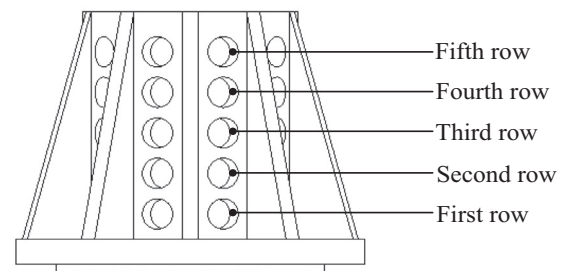
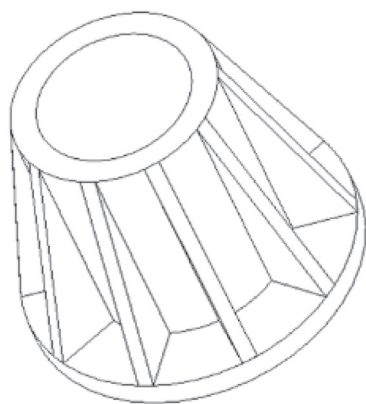
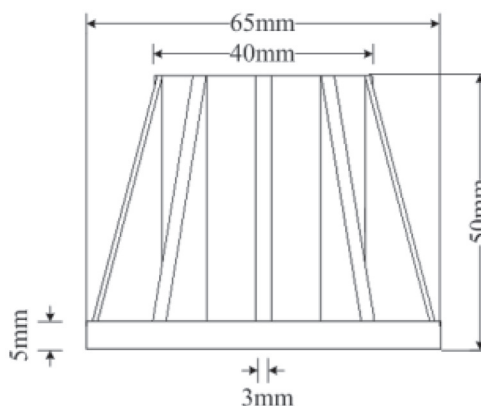


Fig. 2. Holing mode of the holed design.



(a)



(b)

Fig. 1. Finned lighting device; (a) device structure, and (b) device size specification.

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