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Influence of electrode configuration on the heat transfer performance of a LED heat source

Ing Youn Chen [a], Chien-Jen Chen [a], Chi-Chuan Wang [b],*

[a] Department of Mechanical Engineering, National Yunlin University of Science and Technology, Yunlin 640, Taiwan
[b] Department of Mechanical Engineering, National Chiao Tung University, Hsinchu 300, Taiwan

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ABSTRACT

In this study, the effects of electrode configuration on the cooling of LED are presented. A total of six needle type electrodes, including sharp, 0.08, 0.12, 0.37, 0.49 R and flat tip, are used to generate ionic wind for cooling of the LED. The effects of electrode configuration, vertical separation height, and tilt angle on the cooling performance of a LED are reported in this study. It is found that the thermal resistance is reduced with the supplied voltage and a maximum 50% reduction is achieved before the spark-over voltage. For the same supplied voltage, the thermal resistance with a larger vertical separation is also higher. However, the operational range is also longer. The effect of tilt angle on the cooling performance of LED depends on the supplied voltage. With a supplied voltage being less than 6.5 kV, it is found that the thermal resistance is increased when the tilt angle is reduced with a tip radius of 0.12 R. However, the trend is reversed when the supplied voltage is higher than 6.5 kV where the thermal resistance of a smaller tilt angle is lower than that of a larger tilt angle. For the same mesh ground, the effect of electrode configurations cast little influence on the final thermal resistance. All the electrodes show an approximately 50% reduction of thermal resistance in association with its original thermal resistance. However, the corresponding threshold voltage and operational voltage differs significantly. The threshold voltage is lowest for the sharp needle and is increased with the rise of tip radius. On the other hand, the corresponding operational range becomes narrower when the tip radius is increased. Yet the spark-over voltage is also insensitive to change of electrode configuration.

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1. Introduction

The light-emitting diode (LED) is a semiconductor light source that emits light at a specific wavelength. When compared to fluorescent and incandescent lighting, LEDs feature fast response time, simple structure, environmental benign, vivid colors, high energy efficiency, longevity and easier to put into mass production. Hence, LEDs are gradually replacing traditional light sources in every aspect of lighting applications for its versatile benefits. LED light has a high energy efficiency because the energy of electrons is directly converted to light energy at the p–n junction. However, practical LED converts only 15–30% power input into light, leaving 70–85% energy into heat. The heat dissipation inevitably raises the p–n junction temperature, which decreases the allowable current and optical power. In addition, the lifespan of LED lights decreases when they are exposed to high temperatures for a long period of time. Therefore, effective thermal management of the LED lighting is quite essential to avoid failure of the LEDs [1]. This is because that it had been reported that the optical output of the LED is sharply degraded with the increase in junction temperature because the high temperature significantly influences the reliability and durability of the LED [2]. In contrast to other lighting sources; radiation heat transfer barely contributes to heat dissipation for LED due to its relatively low die temperature as relative to an incandescent lamp [3]. Hence thermal management of LEDs depends mainly on both conduction and convection heat transfer. The former, which determines the thermal resistance from LED junction to substrate, plays essential role in spreading heat from a tiny LED die to its packaging substrate, while the latter is mainly responsible for the heat transfer from substrate to ambient [1].

In practice, passive methods incorporating natural convection heat sinks such as plate fin, pin fin and radial fin (e.g., [4–6]) are mostly adopted for heat transfer augmentation for LED cooling. Yet some active methods such as microjet array cooling, liquid-cooling, thermoelectric cooler, and oscillating heat pipes are also feasible techniques that efficiently dissipate heat out of the high

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* Corresponding author. Address: E474, 1001 University Road, Hsinchu 300, Taiwan. Tel.: +886 3 5712121x55105; fax: +886 3 5720634.
E-mail address: ccwang@mail.nctu.edu.tw (C.-C. Wang).

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Nomenclature

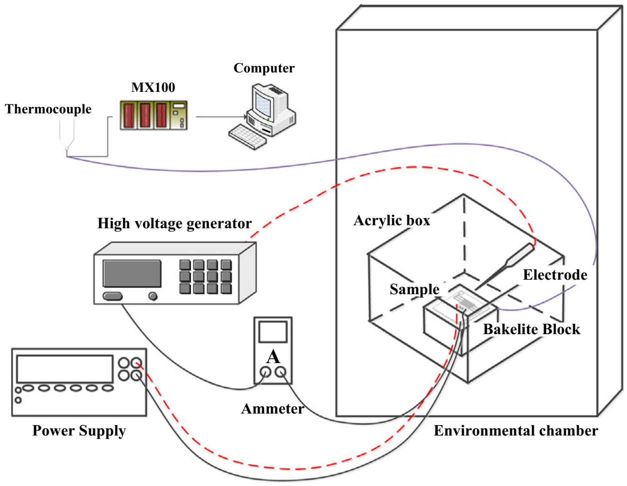
A	surface area (m^2)
h	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
P	LED power input (W)
Q	heat transfer rate (W)
Q_a	actual heat transfer rate (W)
Q_l	heat loss (W)
T	temperature difference (K)
R	tip radius (m)
RH	relative humidity (%)
R_{th}	thermal resistance ($K\ W^{-1}$)

power LEDs (e.g., [7–10]). Despite the foregoing active methods show effective heat removal in high power LEDs, concerns of noise and vibration resulting from the moving parts of these active methods still prevail. In this regard, rather than using mechanical devices to promote cooling, ionic wind featuring the benefit of forced convection but free of noise concerns is one of the potential candidates [11,12]. This would certainly simplify the design and increase the reliability of the cooling module for LED devices due to the lack of moving parts.

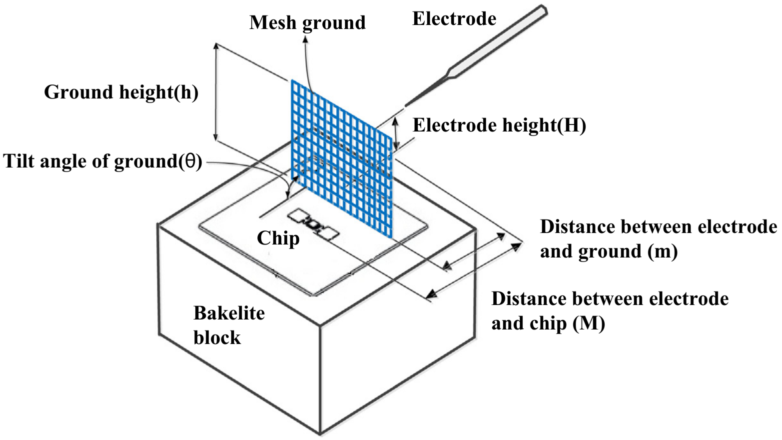
Chen et al. [11] had examined various electrode types, including point, line, and mesh type, on the cooling efficiency of the LED. They showed that the thermal resistance of a LED die can be reduced as much as 50%, yet the point electrode with negative polarity along with the mesh ground electrode gave the best overall cooling performance. In this study, efforts are made further to investigate the configuration of the point electrode on the cooling of LED die. It would be shown later in the investigation that the configuration of the point electrode plays essential role in the operation of cooling of LED.

2. Experimental apparatus and data reduction

The experimental setup consisting of an environmental chamber, a LED die attached on a ceramic substrate, and a power supply



(a) Schematic of the environmental chamber.



(b) Schematic of test section and the arrangements of electrodes.

Fig. 1. Schematic of the test facility and test section.

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