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Enhanced cooling for LED lighting using ionic wind

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ABSTRACT

This study employs ionic wind to augment heat transfer of a LED mounted on a substrate. The size of the LED chip is 0.9 mm × 0.9 mm with a nominal power of 1 W. A needle type electrode is used to generate ionic wind with the applied voltage ranging from 4 to 11 kV. The effects of aligned angle, electrode polarity, separation distance, and ground configuration on the thermal resistance of the LED substrate are examined in this study. For the same applied voltage, it appears that the thermal resistance for the negative polarity is lower than that for the positive one and the negative electrode also has a wilder operation range. The thermal resistance can be reduced as much as 50% in the test range. The thermal resistance is slightly reduced when the aligned angle is increased from 0° to 20°, but a further increase of aligned angle casts no further reduction on the thermal resistance. It is found that the influence of vertical separation distance between the needle and ground electrode is moderately higher than that of horizontal separation distance. Test results also indicate that the mesh ground electrode shows moderately lower thermal resistance than those of point or line electrode.

1. Introduction

Thermal management is one of the most important issues to ensure operational stability of LED lighting applications, and it becomes more severe when the power is further increased. Currently high-power, high-brightness LEDs had penetrated into almost every aspect of lighting applications [1,2]. High-power LEDs in operation can produce high luminance, but they also generate significant heat at the same time. The heat raises severe problems to maintain a low LED die temperature. It had been reported that the optical output of the LED is sharply degraded with the increase in junction temperature [3] because the high temperature significantly influences the reliability and durability of the LED [3–5]. 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 [6]. 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 [7].

Cooling of LED is primarily via convection and conduction. The latter involves heat spreading across the bonding interface [8,9]. In common implementation of LED cooling with regard to convection, passive methods incorporating natural convection heat sinks such as plate fin and radial fin (e.g., [10,11]) are the mostly adopted methods. In addition, some active methods are also available in heat removal, such as microjet array cooling system for cooling of a high-brightness LED array [12,13], liquid-cooling system, thermoelectric cooler, and oscillating heat pipes are also feasible techniques that efficiently dissipate heat out of the high power LEDs [14–17]. Though the foregoing active methods show effective heat removal in high power LEDs, concerns of noise and vibration for these active methods remain. Therefore, rather than using mechanical devices to promote airflow for active cooling, the forced convection can also be implemented without any moving part such as using an electro-hydrodynamic (EHD) approach, where no rotational or moving mechanism is involved. This would certainly simplify the design and manufacture of cooling module for LED devices.

Forced convection derived from ionic winds had been discovered for more than a century. It was not until in the 1960s did the ionic winds came into notice as a means for thermal management. There had been intensive studies focusing in using the EHD technique to augment the heat transfer performance of the heat sinks under natural convection (e.g., [18–21]). The previous efforts aimed at macro scale heat transfer augmentation under natural convection. Notice that the size of LED die is rather small and

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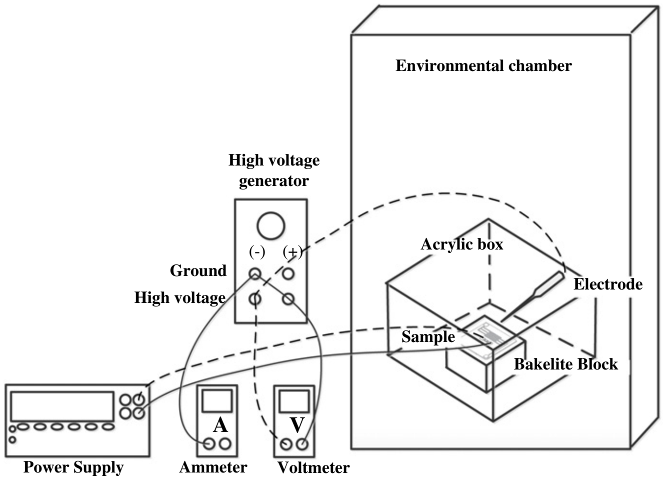
Nomenclature

A	proportional constant for Townsend like relation for positive polarity, A volt^{-2}
A^{+}	proportional constant for Townsend like relation for positive polarity, A volt^{-2}
A^{-}	proportional constant for Townsend like relation for negative polarity, A volt^{-2}
E	electric field, V m^{-1}
H	height, mm
i	corona current, μA
h	height of the electrode (relative to substrate), mm
k	thermal conductivity, W m^{-1} K^{-1}
L	length, mm
P	power, W
Q	rate of heat transfer, W
Q_a	actual heat dissipation, W
Q_l	heat loss from the bakelit, W
R	electrical resistance, Ω
R_{th}	thermal resistance, °C W^{-1}
RH	relative humidity, %
T	temperature, °C
$T_{ins,c1}$	measured temperature at the top of the bakelite, °C
$T_{ins,c2}$	measured temperature at the bottom of the bakelite, °C
ΔT	temperature difference between LED and ambient, °C
V	applied voltage, volt
V_0	threshold voltage, volt
dx	distance between the measured temperatures on the bakelite, °C
θ	aligned angle, °

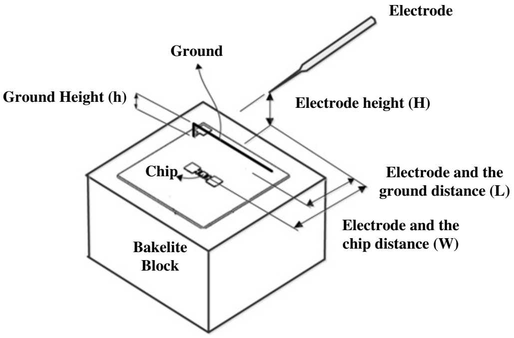
normally possess an extraordinary spreading resistance. In this regard, it would be beneficial to employ EHD near the LED die for effective lifting of the magnitude of the spreading resistance. Hence it is interesting to examine the influence of electrode arrangements, such as aligned angle, distance, and ground electrode configuration on the thermal resistance of the LED chip. The objective of this study is to clarify the effect of relevant parameters of such EHD system.

2. Experimental apparatus and data reduction

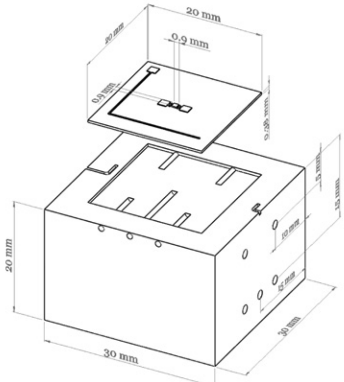
The experimental setup consisting of an environmental chamber, a LED die attached on a ceramic substrate, and a power supply system, as well as a data acquisition system, is schematically shown in Fig. 1a. In order to maintain a constant and uniform ambient temperature throughout the chamber without any fan during the experiment, an environmental chamber having a volume of 0.5 m



(a) Schematic of the test facility.

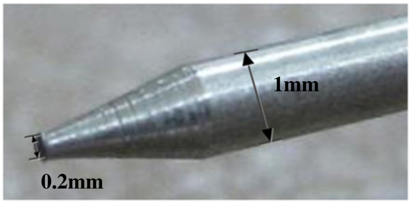


(b) Schematic of the test section.



(c) Detailed dimension of the LED chip and location of the installed thermocouples.

(d) Point electrode used in this study.



(e) Dimensions of the point electrode.

Fig. 1. Schematic of the test facility, bakelite, and the point electrode.