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Research Paper

Experimental study of high power LEDs heat dissipation based on corona discharge

Jing Wang [a,*], Yi-xi Cai [a], Wei-wei Bao [a], Hui-xia Li [a], Qian Liu [b]

[a] *School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang, Jiangsu Province, China*
[b] *Proving Ground for Construction Machinery & Refit Military Vehicles of China Academy of Machinery Science& Technology, Beijing, China*

HIGHLIGHTS

- A novel needles-to-net ionic wind generator for LED cooling was presented.
- Ionic wind generator has good performance for high power LED cooling.
- The discharge distance is the most influential factor for cooling performance.
- The negative corona discharge demonstrated better cooling performance.

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ABSTRACT

High power light-emitting diodes (LEDs) consume most of the applied power as heat, which leads to a high junction temperature; thus, an efficient cooling device is needed. Most of the developed cooling systems face constraints such as cost, consumption, and noise, leading to low work efficiency. In this study, a needle-to-net type ionic wind generator based on corona discharge is suggested for high power LED cooling. The LEDs' junction temperature was calculated by measuring the case temperature, which is called the pin-temperature measurement method. The characteristics of ionic wind in various electrode arrangements or electrical parameters were analyzed, and the case temperature changes induced by ionic wind were measured under various conditions for analysis. The experimental results indicate that the designed ionic wind generator had good cooling performance close to cooling fan, coupled with lower energy consumption and less mechanically induced noise. The maximum ionic wind velocity was measured to be 2.97m/s at a 15 mm discharge distance and 17 kV applied voltage.

1. Introduction

LEDs are a great alternative to conventional general lighting because they are environment-friendly, power saving, and long lasting [1,2]. Currently, the highest luminous efficiency of a single high power LED chip has reached 303 lm/W at the laboratory level [3,4]. However, it still does not fit all practical applications, such as an automotive headlamp, which needs more than 1000 lm [5–7]. Multi-chip LED modules are excellent candidates for such application; however this can result in an increase of the junction temperature, which degrades the performance of the LED. Passive methods of incorporating natural convection heat sinks are adopted mostly for the heat transfer augmentation in LED cooling. Yet some active methods such as micro-jet array cooling, liquid cooling, thermoelectric cooler, and oscillating heat pipes are also feasible techniques that can dissipate heat out of the high power LEDs efficiently [8–10]. The disadvantages of these methods such as high cost, complex design, and decrease of efficiency have greatly restricted their applications.

Corona discharge has been widely used recently in dust removal, sterilization, drying, material surface modification, and heat dissipation [11–14]. This has resulted in it becoming a research hotspot. Ionic wind, which is produced in the inhomogeneous electric field of corona discharge, featuring the benefit of forced convection but free of noise, is one of the potential candidates for cooling [15,16]. Ionic wind research for heat dissipation has actively progressed in the last few decades. Moss and Grey [17] investigated the effect of corona wind on heat transfer enhancement experimentally, positioning a wire electrode at the center of a circular tube and observing a noticeable heat transfer enhancement. Marco and Velkoff [18] used a point-to-plane configuration to measure the effect of corona-induced secondary flow on heat transfer. They observed that the convective heat transfer coefficient was increased five times compared to free convection. Kasayapanand [19] analyzed the cooling performance of ion wind for a vertical fin array using the computational fluid dynamics technique. Chen et al. [14] verified the cooling performance of ion wind for LED devices by measuring the thermal resistivity of the LEDs. They showed that the thermal resistance of

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[*] Corresponding author. Tel.: +86 511 88780590; fax: +86 511 88780590.
E-mail address: jackywang03@163.com (J. Wang).

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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. Go et al. [20] numerically investigated a micro-scale ionic wind as a method of generating local boundary layer distortion to enhance convective heat transfer. Their model described two electrodes on a flat plate, exposed to an external bulk flow. This method provided approximately 50% local heat transfer enhancement. Molki and Bhamidipati [13] performed an experiment to measure the enhancement of convective heat transfer in developing a region of circular tubes using a corona wind. Their study was focused on the transitional and lower range of turbulent flows. The maximum enhancement of heat transfer coefficient for the circular geometry was 23% based on their experimental results. Shin et al. [21] suggested a needle to parallel plate ionic wind generator; the cooling performance of ion wind was analyzed by measuring the temperature distribution, and was quantitatively verified by calculating the heat transfer coefficient and enhancement factor.

In this study, efforts are made further to investigate the configuration of a needles-to-net ionic wind generator and the input electrical parameters on the cooling of high power LEDs by experiment. Heat drop and ionic wind velocity change are used to evaluate the system's cooling performance. However, the high-voltage conversion may be the obstacle in practical application.

2. Ionic wind and heat transfer

Generally, the study of ionic wind heat transfer enhancement starts with the electric field force of fluid. For the incompressible fluids, it should satisfy the momentum equation according to the theory of heat transfer [22].

$$\rho\frac{d\bar{v}}{dt}=-\nabla p+\rho\bar{g}+\mu\nabla^2\bar{v}+\bar{F}_e \tag{1}$$

where the electric field force leads to the formation of a unidirectional airflow movement and ionic wind.

The electric field force of the fluid can be expressed as follows according to the theory of electromagnetism [22].

$$\bar{F}_e=q\bar{E}-\frac{1}{2}E^2\nabla\varepsilon+\frac{1}{2}\nabla\left[E^2\left(\frac{\partial\varepsilon}{\partial\rho}\right)_T\rho\right] \tag{2}$$

On the right side of the equation, the first item is the Coulomb force, which acts on the space charges in the electric field, also known as the electrophoretic force. The direction of the electrophoretic force is dependent on the polarity of free charge and electric field direction. The second item is dielectrophoretic force, which is induced by the space change of dielectric constant. The third item is electrostrictive force, which is related to the electric field intensity and the spatial distribution of dielectric constant. In the present study, the influence of the dielectrophoretic force and the electrostrictive force to the electric field force could be neglected because the flow field is an airflow field. It is a single-phase flow field and there is no interface; assumption has been made that the dielectric constant distributed uniformly in the space [23]. So the Coulomb force is the main factor that controls the moving speed of the space charges in the discharge area.

$$\bar{F}_e\approx q\bar{E} \tag{3}$$

3. Experimental system

3.1. Experiment apparatus and layout

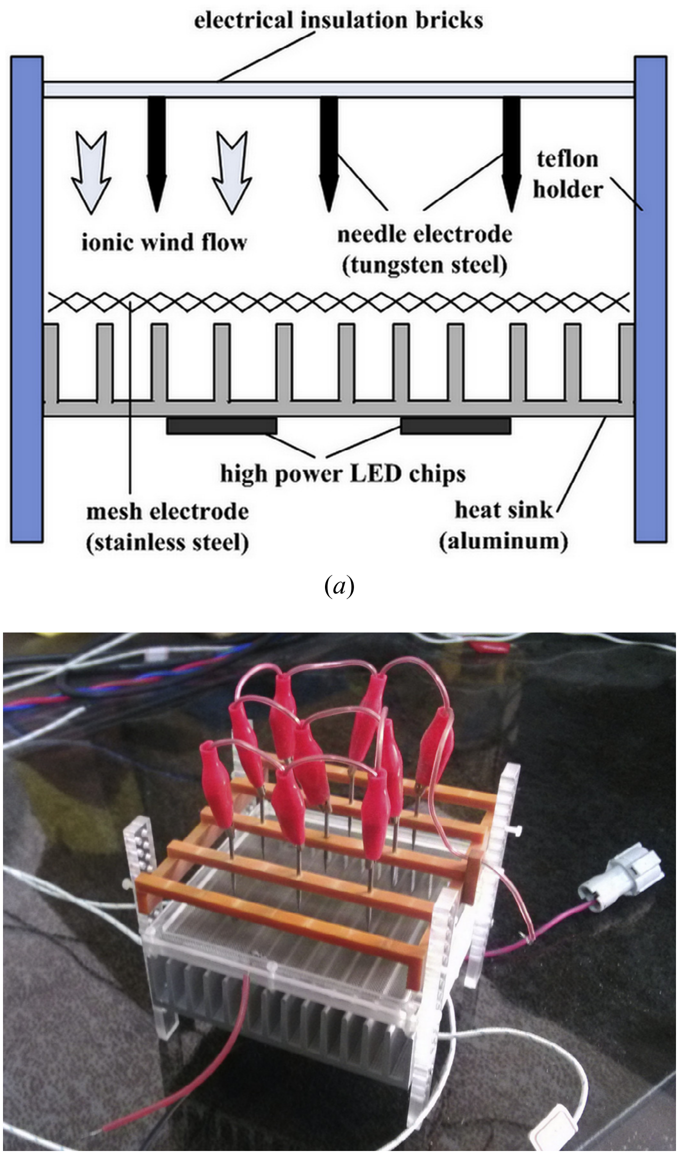

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Fig. 1. Ionic wind cooling system.

Fig. 1 shows the designed ionic wind cooling system. Electrodes of the ionic wind generator are the tungsten steel needle electrode and the stainless steel mesh electrode, respectively. The arrangement of needle electrode, the distance between needle electrode cutting-edge and mesh electrode can be adjusted. Ionic wind in parallel to the direction of the needle electrode will be produced when high voltage is applied. The heat that conducts from the LED chips can be distributed to the fins in a timely manner under the action of ionic wind. The arrangements of needle electrode are shown in Fig. 2.

In this study, the PHILIPS LUXEON Altilon, model type LAFL-C4S-0850, was used. This type of LED chip has a nominal power consumption of 13.7 *W*, and can work within a temperature range of −40~+130 °C, with the maximum permissible junction temperature of 125 °C, and a light-emitting area of 1.06 *mm* × 4.51 *mm* [24]. It was assumed that the ratio of net heat dissipation to total electric power input is 0.8.The experimental setup consists of an environmental chamber, a LED die attached on an aluminum substrate, a power supply system with steady voltage and current for LED chip, a DC high voltage power supply, as well as a data acquisition system, is schematically shown in Fig. 3. In order to maintain