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Research paper

Development of a heat dissipating LED headlamp with silicone lens to replace halogen bulbs in used cars

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HIGHLIGHTS

- We design a high-efficiency LED headlamp with a silicone lens.
- The thermal performance of the LED lamp was experimentally verified.
- The silicone lens shows the same optical characteristics as a halogen bulb.
- We report a LED headlamp that can act as a replacement for halogen bulbs.

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ABSTRACT

LED headlights have been developed for newly produced automobiles, but LED substitutes to replace halogen headlamps in used and second-hand automobiles are nonexistent. Hence, this study developed a high efficiency LED headlight that can act as a replacement for halogen bulbs. To achieve this, a silicone lens capable of producing a light distribution curve identical to halogen, and an LED with similar photochromic characteristics to halogen lamps was developed. Additionally, CFD was applied to optimize the LED's heat dissipation performance. A prototype was produced and its performance was verified through experiment.

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1. Introduction

Light Emitting Diodes (LED) have fast response times and are capable of expressing a variety of different colors. They do not emit in ultraviolet or infrared wavelengths, are efficient compared to other light sources, have superior longevity, can be miniaturized, and are beginning to replace traditional light sources [1]. Despite these advantages, because LEDs convert 75–85% of input electric power into heat, increasing the input power can drastically increase the junction temperature of the LED [2]. The resulting increase in temperature influences the longevity of the LED, and if the junction temperature exceeds the maximum operating temperature, the circuits in the chip are cut and the LED fails [3]. In the case of high power LEDs, this limitation is especially exacerbated. Designing efficient thermal system within the LED is necessary to overcome such limitations.

In an effort to solve the thermal management problem, Wang [4] adjusted the refrigerant ratio to 10–50% within the heat pipes to optimize the total amount of refrigerant. Kim [5] performed numerical analysis on a model with a heat pipe applied to an LED array system and reduced thermal resistance by up to 34%. Jang [6] analyzed the orientation effect for cylindrical heat sinks used to cool an LED light bulb and proposed a correlation to predict the heat transfer coefficient. Lu [7] developed a number of heat pipes for use at varied slope angles to improve the thermal performance of high power LEDs. Maaspuro et al. [8] studied the heat resistance of different heat sinks and adhesives, reaching the conclusion that LED junction temperature can be reduced up to a few degrees if grease with poor thermal conduction is replaced with the best silicone materials.

Recently, as alternatives to halogen lamps such as the one illustrated in Fig. 1, LED headlights have become the focus of research for automobile applications. However, these LED headlights have only seen real application in newly produced

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Nomenclature

h	convective heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K)
L	length of the heat sink fin (m)
Nu	Nusselt number
n	normal vector
P	pressure
$\dot{P}$	power input to the LED (W)
$\dot{q}$	heat flux (W/m^2)
R	thermal resistance (°C/W)
T_j	temperature (°C)
T_{sp}	soldering point temperature (°C)

Subscripts

a	air
amb	ambient
f	fluid
fs	freestream
hs	heat sink
j	junction
j-sp	junction to soldering point
s	solid
sp	soldering point
t	total
w	wall

automobiles, and have yet to be installed in older, used models. The development of a substitutable LED headlight that can be applied to older automobile models, shown in Fig. 2, in place of halogen bulb lights has yet to be accomplished. This is in part due to the fact that the confined space in which the halogen bulbs are installed limits the inclusion of cooling device. As a result, optimization of the cooling device is of upmost importance. Additionally, as LED lights have a different light distribution compared to their halogen counterparts, the development of a new lens that can correct the light distribution to match that of the halogen lamps is also necessary.

This study developed a high efficiency LED headlight that can replace the halogen lights in used automobiles. A silicone lens that distributes light identically to halogen lamps, and an LED with a photochromic characteristic similar to halogen were developed. CFD (computational fluid dynamics) were applied to optimize the thermal management of the LED, and a prototype was produced, after which its performance was verified through experiment.

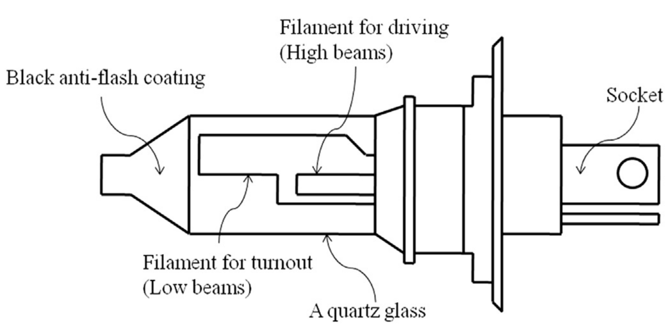

Fig. 1. Schematic of a halogen lamp.

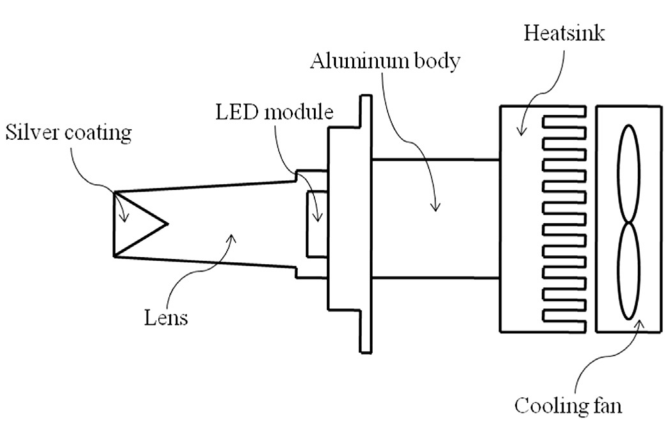

Fig. 2. Schematic of a lens type LED lamp.

2. Numerical analysis and experiments

2.1. Numerical model

The three-dimensional numerical model used in this paper is shown in Fig. 3. The heat sources, the LED chip, PCB (printed circuit board), and silicone mold were simplified for numerical analysis. Fig. 4 is a three-dimensional model of the heat sink used for cooling of the LED. Fig. 4 (a), (b), and (c) show a plate-fin type, pin-fin type, and radial-fin type heat sink, respectively. Each heat sink is designed to be small enough to be able to replace existing halogen bulbs. Fig. 5 details the specific dimensions of the heat sink used in this study. The plate-fin type sink has 77 evenly spaced plate-fins, each of which is 2.5 × 1 mm^2 wide and 5 mm tall. The pin-fin type sink has 121 pins placed evenly along the sink's base, which have a diameter of 2.5 mm and a height of 5 mm. Finally, the radial-fin type sink is composed of 36 plates placed perpendicularly around a cylindrical base; each plate is 13 mm long and 5 mm tall. The fins are spread around the cylinder at a constant angle.

2.2. Numerical method

The flow considered in this study is three-dimensional, steady-state, turbulent flow, hence the k-ε model was used. The DO (discrete ordinates) model was used to analyze radiation. The

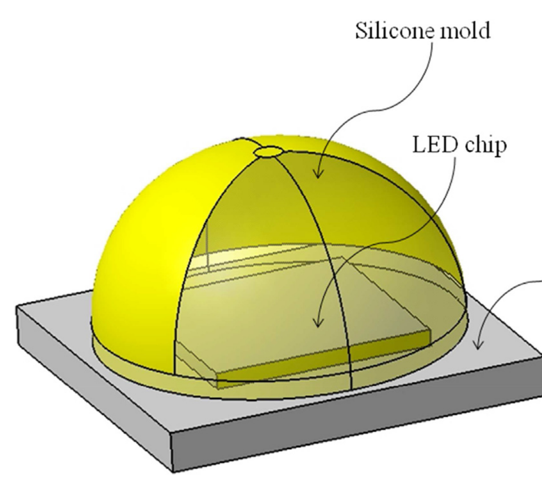

Fig. 3. Schematic of a simplified LED module for numerical analysis.

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