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A STUDY ON THE THERMAL PERFORMANCE OF LED SIGNAL BULBS FOR VEHICLES

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ABSTRACT

LED (light emitting diode) converts over 80 percent of the input power into heat. This heat increases the junction temperature, which could result in reduced lifetime of the LED due to an excessive thermal load. This study aims to optimize the shape of a heatsink in order to develop a LED signal bulb that can replace the conventional halogen bulb equipped in vehicles. To this end, the thermal performance is predicted through a numerical analysis and verified with a prototype of the LED signal bulb for vehicles. A numerical analysis shows that Case 3 provides the most efficient thermal performance; it is also verified through experiments that the input power for the LED can be increased up to 6W without problems.

Keywords: LED, signal bulb, heatsink, junction temperature, thermal management performance

1. INTRODUCTION

LEDs (light emitting diodes) are now considered the next generation car lights thanks to their longer lifetime and better luminance efficiency [1]. Replacing the existing lighting source with LED lights can be significantly beneficial in terms of saving energy [2]. Against this backdrop, many car-owners want to change their car lights to LED lights, and, reflecting this trend, car-makers are now actively employing LED lights for their newly-launched vehicles.

LED lights use approximately 20 percent of the input power to emit light and the remaining 80 percent of the power is converted into heat. This heat increases the junction temperature, which may result in reduced luminous efficiency, deterioration of the fluorescent body [3], chip failure, separation of layers, and disconnection, ultimately leading to shorter lifetime of the LED. To prevent the aforementioned from occurring, sufficient thermal performance should be secured when using the LED as the luminous source. However, installing additional thermal performance supporting device is difficult for vehicles due to the limited space. These conditions make the thermal performance of the heatsink even more important when equipping a vehicle with LED lights.

Jeong *et al.* [4] attempted to maximize the thermal performance of the heatsink by making the air circulation more efficient with an optimized heatsink pin shape. Christensen *et al.* [5] demonstrated that the thermal performance can vary, depending on the arrangement of the high-power LED. Jung *et al.* [6] successfully developed a LED headlamp prototype with an optimized heatsink and cooling fan in an attempt to replace the existing halogen bulbs for vehicles. Wang *et al.* [7] designed a TEC cooling system and applied it to high-power LED headlights. As shown in a number of studies conducted thus far, securing sufficient thermal performance for LED lights is a key element when employing the LED as the luminous source. This study aims to optimize the shape of the heatsink, considering the manufacture and weight of the heatsink, with the goal of developing 4.5W-graded LED signal bulbs. In so doing, the thermal performance is predicted through a numerical analysis, a prototype is developed, and its performance is verified in experiments.

2. NUMERICAL ANALYSIS

This study designed three types of LED signal bulbs in consideration of the manufacture and the weight of the heatsink, using CATIA [8] for shape design. Figure-1 shows the 3D models of the LED signal bulbs. Case 1 employs a cylinder-shaped pin, and the size of the pin increases in Cases 2 and 3.

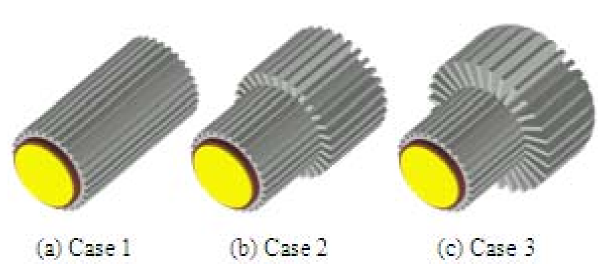

Figure-1. 3D models of LED signal bulbs.

ICEM-CFD [9] was used for grid generation and Fluent [10] for the thermal analysis. In the numerical analysis model, natural convection was assumed and a pressure outlet boundary condition was used allowing the external air to move in and out freely. The adjacent temperature of the LED module was set at 40ºC given the actual conditions inside a vehicle. The input power was 4.5W, and was increased by 0.5W. The thermal resistance

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at the junction of the LED and PCB was assumed as 0.8 ^{o}C /W, and the marginal temperature of the LED junction temperature was 120 ^{o}C.

3. EXPERIMENTAL METHODS AND EQUIPMENT

The following formula was used in predicting the junction temperature since it cannot be directly measured at the junction of the LED module and PCB.

$$T_J=T_S+R_J \times W_{in} \quad (1)$$

T_J is junction temperature, T_S the temperature of the solder point at thermal equilibrium, R_J thermal resistance, and W_{in} the input power. Thermal resistance is one of the core elements for the junction temperature, determined by the material and structure that the LED module employs. The thermal resistance can be calculated through the following formula:

$$R_J=L/\rho A \quad (2)$$

In this formula, L represents the length of the LED module, A the cross-sectional area, and ρ the thermal conductivity; in this study, ρ was set at 0.8^{o}C/W, a value measured by the LED manufacturer. Figure-2 shows the LED signal bulb for Case 3. The LED used here has 400 lm(luminous flux) at 4.5W; 4.5W is applied to the LED module with a DC power supply (DRP-303D). The junction temperature is calculated using Formula (1) by measuring temperature at the soldering point when the thermal equilibrium is achieved. When measuring the soldering point temperature, the ambient temperature was 20.6 ^{o}C and compensated to make it the same as the temperature assumed in the numerical analysis models. To prevent heat loss as much as possible, the temperature was measured in a sealed acrylic chamber. Figure-3 is a schematic diagram of the thermal performance measuring unit used in the experiments.

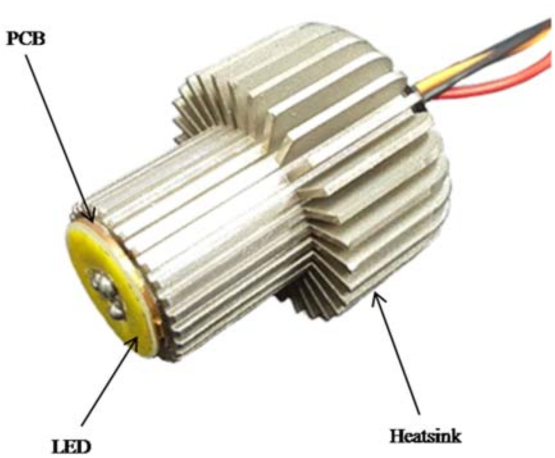


Figure-2. Prototype of the signal bulb.

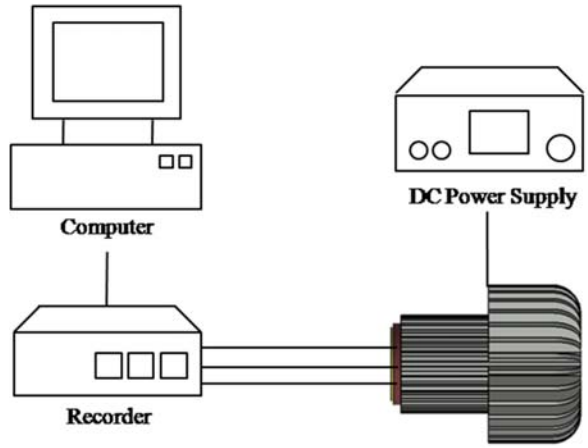
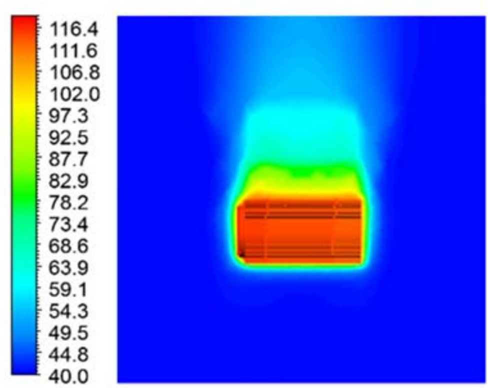


Figure-3. Schematic diagram of the experimental unit.

3. RESULTS AND DISCUSSIONS

3.1 Thermal performances by heatsink

Figure-4 shows the temperature distribution at thermal equilibrium after the heatsink applied 4.5W to the signal bulbs. The junction temperatures for the cases stood at 118.7^{o}C, 110^{o}C, and 102.5^{o}C for Cases 1, 2, and 3, respectively. Although none of the models reached the marginal junction temperature of 120^{o}C, Case 3 demonstrates the best thermal performance. Table-1 shows the weights and the heat transfer areas of the cases. Case 3 shows the most efficient thermal performance because it has the largest heat transfer area.



(a) case 1

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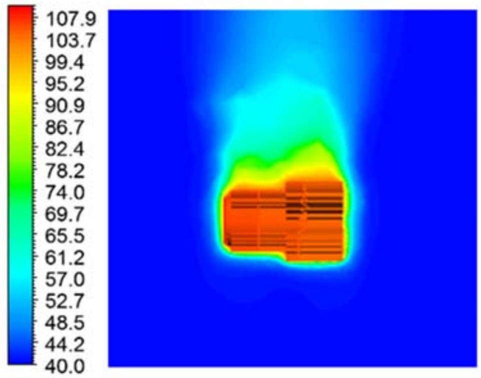
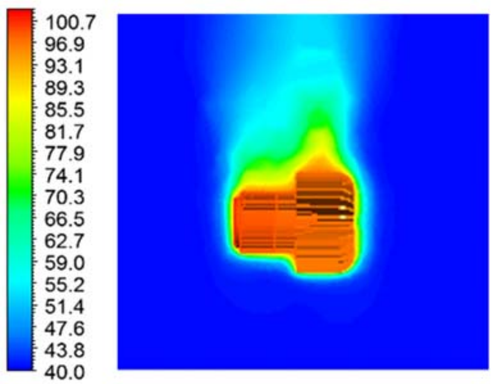


(b) case 2



(c) case 3

Figure-4. Contours of the temperature.

Table-1. Mass and heat transfer area of the cases.

	Case 1	Case 2	Case 3
Mass	0.012 kg	0.013 kg	0.015 kg
Heat transfer area	0.005 m^2	0.01 m^2	0.014 m^2

3.2 Junction temperature by input power

Figure-5 displays the junction temperature of the cases for different input power. Case 1 exceeds the marginal junction temperature when approximately 5W of power is applied while Case 2 exceeds this temperature at around 5.5W. Case 3, which showed the best thermal performance, however, does not reach the junction temperature limit until the input power is increased to 6W, demonstrating stable performance without additional thermal radiation devices. Despite its outstanding performance, however, there should be additional measures to use Case 3 with input power over 6W, such as using a bulb socket as an additional heatsink.

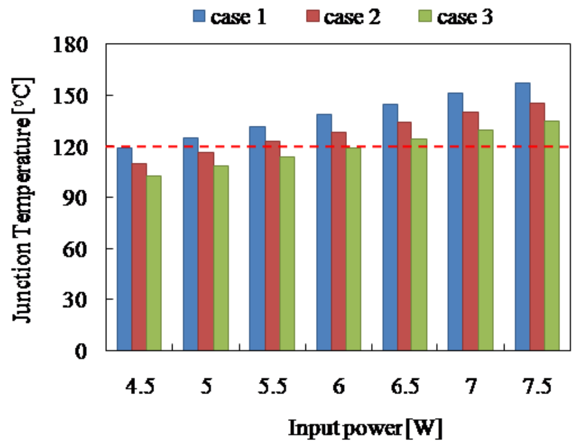


Figure-5. Variation of junction temperature with the input power.

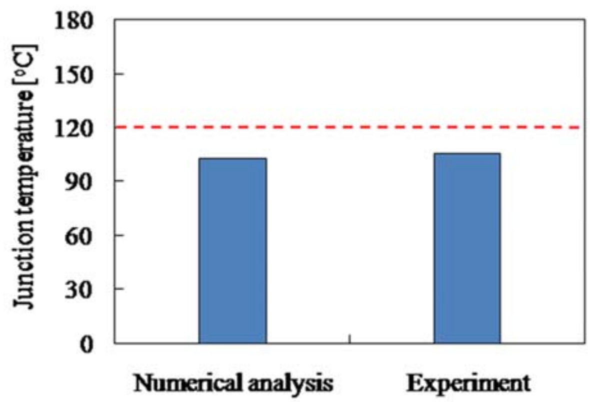


Figure-6. Junction temperature of numerical analysis and experiment for input 4.5W.

3.3 Experiments on thermal performance

Figure-6 compares the numerical analysis results and the junction temperature measured in the experiments when the input power was 4.5W. The experiment in which a prototype (Case 3) was used showed junction temperature of 105.6 °C the experimental error was as small as 2.8 percent when compared to the results of the numerical analysis. Therefore, the thermal performance of the 4.5W LED signal bulb was successfully proven through the experiments.

4. CONCLUSIONS

The aim of this study was to develop a LED signal bulb that can be used in vehicles instead of the conventional halogen bulbs. To this end, an optimized prototype was developed through the process of heatsink shape design and a thermal radiation analysis, and the thermal performance of the prototype was verified in the experiments. The conclusions of this study are as follows:

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a) When 4.5W of power is applied to the LED, Case 3 showed the most optimal thermal performance, owing to its largest heat transfer area.

b) As the input power rises, the junction temperature increases accordingly. Case 3 operated at the maximum input power of 6W when the marginal junction temperature was set at 120ºC.

c) The junction temperature measured in the experiment conducted with the prototype (Case 3) was 105.6ºC. This verifies that a signal bulb offering sufficient thermal performance has been successfully developed.

Additional thermal performance tests should be followed on LED bulbs with a lens and fixing socket attached. Studies on a wide color gamut and optical properties should also be conducted.

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