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Effect of potting materials on LED bulb's driver temperature

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ABSTRACT

This work presents a simple and effective technique to decrease the driver temperature by filling the potting materials into space between driver and the interior wall of a LED bulb's heatsink. The thermal exchange between the LED bulb, including LED chips, driver, heatsink, potting materials and the ambient were studied using the finite element method. The effects of potting materials on LED chips' temperature were investigated by thermal simulation and experiment. We found that the driver's temperature depends strongly on the thermal conductivity of potting materials. We also conducted simulation to find the suitable thermal conductivity value of potting materials for LED bulb.

1. Introduction

High power LED bulb has been presented as an important candidate in the replacement of traditional light bulbs due to their long life, high luminosity and low energy consumption. However, a large amount of electrical power consumed by LED packages is converted into heat (from 75% to 85%) instead of light [1,2]. In addition, the LED driver also generates significant amount of heat during operation. This extra generated heat, if not effectively dissipated, can contribute to the increase of the LED junction temperature and the driver board temperature. It is well known that elevated junction temperature could lead to reliability problems such as low quantum efficiency, wavelength shifts, short lifetime, and even catastrophic failure [3,4]. On the other hand, high driver's temperature could shorten the lifetime and degrade performance of electronic components [5]. Therefore, the effective thermal management of LED and driver board is obviously the key for LED performance improvements.

Driver board of LED bulb contains different electrical components such as driver chip transformer and capacitor. The lifetime of a LED driver is mainly determined by the capacitor lifetime. The capacitor lifetime drops by a half for every increase of 10 °C in operating temperature. This situation makes thermal management of these components critical to increase lifetime of driver board [6]. To dissipate heat from driver effectively, two main techniques are used in thermal management design. First approach focusses on energy-efficient circuit design to reduce heat generated in the driver [7]. Second approach develops thermal solution such as effective conduction and/or convection of heat in to ambient surroundings convective/conduction cooling to reduce LED driver temperature [8].

Despite of recent advance in thermal management of LED lamp, only a few work has been focused on thermal management of driver board in high power LED bulb such as LED downlight [9], LED lamp [10] and LED luminaire [11–13]. Perpina attempted to model the main components of driver board of LED lamp and investigated heat transfer process using finite element method (FEM) [14]. They predicted that placing the driver board inside the LED lamp could increase temperature in driver board (e.g. up to 15% for LED board) [15]. Recently, it is shown that potting material with the thermal conductivity of 0.2 W/mK could reduce driver board temperature because it conducts heat to the inner surface of the heat sink more effectively [16]. As a result, potting materials can be considered as a new route to improve the lifetime and reliability of the drivers. Although, potting materials improves heat dissipation rate of LED, its effect on LED temperature and thermal distribution has not studied systematically. In this work, we investigate the role of different potting materials in reducing temperature of driver board by using FEM thermal analysis. We find that the temperature of driver board is decreased dramatically when using potting materials with thermal conductivity in the range from 0.1 to 1 W/mK. Results indicate that appropriate thermal conductivity of potting material should be > 1 W/mK for an effective heat dissipation.

2. Model and method

In this work, the thermal distribution of a typical high power 16 W

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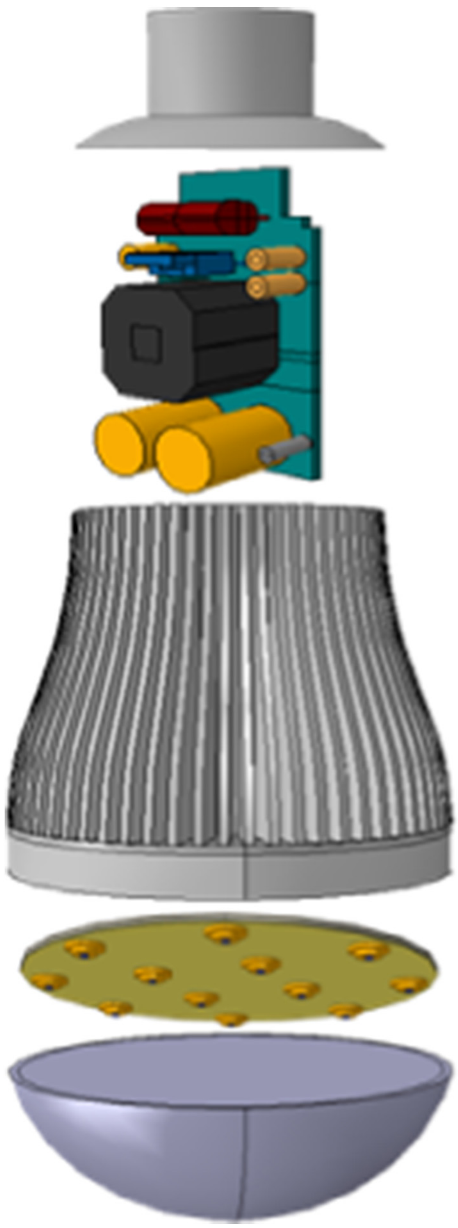

Fig. 1. Modeling of high power LED bulb.

Table 1
Material properties and dimensions of LED bulb's components.

Component	Material	Thickness (mm)	Conductivity (W/mK)
Cover	Polycarbonate		0.2
Die	Si	0.035	124
Die-attach	Au-20Sn	0.05	57
Heat slug	Cu	1.5	389
Solder paste	Glue	0.05	2
Copper layer	Cu	0.127	389
Dielectric layer	Resin	0.075	1.1
Metal core layer	Al alloys	1	166
TIM	Epoxy glue	0.1	1.0
Heat sink	Al alloys		166

LED bulb is numerically calculated using the commercial software Abaqus 6.10. Fig. 1 presents the LED bulb model. Beside components that are already annotated in the figure, it is worth detailing the LED module. In this component, LED dies are attached to heat slugs using a layer of die-attach material. Heat slugs are integrated to a metal core printed circuit board (MCPCB) using solder paste. The MCPCB itself consists of three layers: a copper layer, a dielectric insulator layer and an aluminum alloy layer. Next, the MCPCB is connected to the heatsink via a thermally interface material (TIM) layer. The thermal conductivity and the thickness of materials used in simulation are listed in Table 1 [1]. All materials are assumed to be homogeneous and isotropic. Their thermal conductivities are assumed to be independent of temperature.

Table 2
Thermal conductivity of LED driver components [14].

Component	Conductivity (W/mK)
IC	7.5
Resistor	5
Rectifier bridge	2.5
Capacitor	6
Diode	6
Transformer	5
FR4 board	4
Other	2

The LED bulb also contains a driver board with an IC and other electronic components. Main electronic components of driver board are modeled as shown in Fig. 1. Thermal conductivities of driver components are presented in Table 2 [15]. Thermally conductive potting materials are used to fill up into the space between the driver board and the heatsink. Although LEDs have p-n junction layers and thin metallization layers, we exclude these layers in the model because it could cause high ratio mesh element and time consuming in simulation. In this case, the die temperature can be estimated as the junction temperature. Phosphor layer, encapsulate, solder joint and other electrical connection are not considered in the model.

We assume that natural convection around heatsink and the effective convection coefficient is 3.5 $W/m^2 K$ at 25 °C ambient temperature [3,13,17]. The boundary conditions of die, heat slug and MCPCB surface are adiabatic. We assume that 85% of LED electrical power input is converted to reluctant heat [18], therefore, total heat source on 12 LEDs is 11.56 W. Total heat source on driver input power is 2.1 W as calculated from measurements. Because radiation energy of high power white LED is moderate, radiation phenomena are not included in thermal simulations. The heat transfer used in simulations is governed by steady state heat transfer Eq. (1) [17,19].

$$k\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right]+Q-hA(T-T_{amb})=0 \quad (1)$$

where k is the thermal conductivity (W/mK), Q is the heat generation per unit volume (W/m^3), h is the convective coefficient (W/m^2K), A is the area (m^2), T is the temperature (°C).

Meshing is an important step that directly contributes to the accuracy and the running time of simulation. LED chips and heat slug are finely meshed because heat loads are applied in these regions. The model is meshed by using hexagonal linear brick (DC3D8) with the total number of elements being 542,163.

Experimentally, thermal couples are used to monitor LED bulb temperature at different positions: solder points and fin of heat sink. Thermal sensor is used to measure temperature of driver's components. Thermal distribution is recorded by using an infrared thermal camera FLIR E40.

3. Thermal simulation and measurement

For FEM thermal simulation of the LED bulb, beside the geometries, the thermal properties of materials, it is important to properly determine the heat load distribution, especially the one of the driver board. For this purpose, we conduct a FEM simulation for the LED