

# Research and Optimization Design of Thermal Management for LED

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**Abstract.** LED, a lighting source that has gained popularity in the 21st century, possesses characteristics such as energy efficiency, eco-friendliness, compactness, and durability. However, its electro-optical conversion efficiency remains relatively low, as approximately 80% to 90% of the input power is dissipated as thermal energy. Consequently, the temperature of the LED rises, leading to a decrease in its luminous efficiency. Hence, it is crucial to conduct research on efficient heat dissipation methods for LEDs. We have compiled research plans from various scientific institutions and observed that through optimized design, the heat dissipation capability of LEDs has significantly improved. This improvement has resulted in reduced thermal stress within the chips and packaging, ultimately enhancing their reliability.

**Keywords:** High-power LED Steady-state heat transfer, Fluid-solid coupling simulation, Influencing factors, Optimization design.

## 1. Introduction

Our world is facing difficulties, such as the depletion of resources, the crisis of energy, and the aggravation of environmental pollution. Therefore, we urgently need a clean, energy-saving, and efficient lighting source [1]. LED, as a new and efficient lighting source with many merits, is very suitable for people's needs. LED will gradually supplant traditional light sources and become a new generation of green and eco-friendly lighting sources. With the increasing application of LEDs, we urgently need to develop low-cost and high-brightness LEDs because most of the energy of current LEDs is consumed in the form of heat. LEDs are very sensitive to temperature. If the heat dissipation is not good, it will cause the junction temperature rising, which will not only affect the luminous efficiency of the LEDs but also reduce their life and reliability [2~6]. In addition, there is also a challenge of mismatch between the thermal expansion coefficient of LEDs and packaging materials, which may cause large thermal stress and lead to LEDs chip failure. Therefore, studying the heat dissipation mechanism of LEDs, selecting suitable packaging materials and heat dissipation methods, optimizing their structure design are very important for reducing the junction temperature of LEDs, maintaining their luminous flux, extending their service life, improving their reliability [2~6]. In this paper, we reviewed the research results of domestic and foreign researchers on the working mechanism and performance of LEDs from experiments, simulation and optimization design aspects.

## 2. Current Status of Experimental Research

Researcher Xie Qianwen *et al.* [7] approached the topic from a reliability perspective. They examined the individual effects of packaging, junction temperature, and electrostatics on LED reliability. Additionally, Xie Qianwen conducted experiments on LED packaging processes to assess their impact on product qualification rates and reliability.

Dai Weifeng *et al.* [8] conducted experimental tests to observe temperature changes in surface feature points of high-power LED devices during the transition from initial to normal operation. They compared these results with transient simulation calculations and concluded that the position with the largest deviation between simulated and measured junction temperature is near the luminous vertex of the LED device. However, at other positions, the data from both methods exhibited good agreement with relatively small errors.

Luqiao Yin *et al.* [9] evaluated the thermal performance of various ceramic substrate materials, specifically AlN, Al, and Al<sub>2</sub>O<sub>3</sub>, in multi-chip LED modules. Their assessment involved finite element analysis and electrical testing methods. Both approaches indicated that AlN ceramic substrates demonstrate better optical performance, but their thermal performance can be compromised if heat management is inadequate compared to the other two materials. Nur Hasyimah Hashim *et al.* [10] studied the thermal impact of using high-efficiency thermal paste filled with AlN and BN ceramic particles on high-power LEDs. The results showed that the junction temperature was 2.2°C lower when using AlN thermal interface material compared to BN thermal interface material.

Yang Chu *et al.* [11] conducted experimental tests to evaluate the optical, electrical, and thermal parameters of COB packaged LEDs on various substrate materials, including glass and ceramic. They compared and analyzed the obtained results. The findings indicated that the light output power of COB packaged LEDs on glass substrates was similar to that of ceramic substrates. Consequently, the team focused on studying the thermal conductivity of COB packaging on glass substrate materials. Through the design of a back silver brush and aluminum clamp, the team successfully reduced the substrate temperature. Specifically, when the silver layer thickness was 75µm, the adhesive surface temperature reached its lowest point, and the light output reached approximately 315lm.

Jia Xuejiao *et al.* [12] conducted tests on 10,000 GaN-based white and blue light LEDs using high and low temperature control boxes. Following temperature stabilization, the researchers measured the temperature and other performance parameters of the LEDs. As the temperature gradually increased, the voltage of the LEDs decreased linearly, resulting in a proportional decrease in relative light intensity. The peak wavelength of the LED also increased gradually, shifting towards the red end, with an accompanying increase in the peak half-width. Moreover, the peak half-width of the GaN-based LED at low temperatures was smaller compared to room temperature. The correlated color temperature of the white light LED increased, causing the LED light to become softer and closer to warm colors at lower temperatures.

K.C. Yung *et al.* [13, 14] performed thermal analysis and experimental verification on high-brightness array LEDs packaged on a PCB board under natural convection cooling, using different layout algorithms. The study focused on the operating conditions of the system module, including PCB thermal conduction, heat sink design, and LED layout design. The researchers measured the temperature distribution and heat flow within the LED package. The results indicated that the position and tilt angle of the LEDs had a significant impact on the heat dissipation performance of the LED package. By comparing changes in radiant flux, LED efficiency, and illumination uniformity, the researchers concluded that the new layout method could reduce the surface temperature of an individual LED by more than 10%. Miao Cai *et al.* [15] studied a mixed prediction method for maintaining high-power LED luminous flux. The method evaluates the junction temperature through modeling and temperature measurement to achieve long-term luminous maintenance. Stable and reliable relationships were found between the lamp structure and material, the reference point of the heat sink, junction temperature. The simulation values were verified through precise aging tests. The results showed that the thermal resistance model of the LED lamp in a stable state can be simplified to a one-dimensional model. Therefore, the junction temperature of the LED at any specified operating environment temperature can be quickly obtained, and the method for predicting the luminous maintenance of the LED lamp is efficient.

Yong Tang and colleagues *et al.* [16] developed a novel lead frame for high-power LED devices, known as the cylindrical heat pipe (CHP) lead frame. They directly mounted 42 high-power LED chips on the surface of this lead frame and conducted experimental measurements to evaluate its thermal performance, light emission, and chromaticity. The results indicated that the thermal resistance from the lead frame to the heat sink, at a current of 2800mA, was 0.23°C/W, while the thermal resistance from the chip to the environment was 1.65°C/W. Furthermore, the luminous efficiency of the CHP lead frame LED device reached 66.23 lm/W, which was 19.2% higher compared to the traditional copper lead frame. Additionally, the CHP lead frame exhibited a correlated color temperature transfer value of 381K, representing a 23.5% reduction compared to the

traditional copper lead frame. These findings demonstrated the remarkable advantages of the CHP lead frame in high-power LED lighting applications.

In another study, Yang Weiqiao and colleagues *et al.* [17] conducted experimental research on the thermal sensitivity of LED thermal resistance. They investigated LED devices with different packaging structures under varying conditions of current, substrate temperature, and packaging material. The experimental results revealed that as the current and substrate temperature increased, the thermal resistance initially decreased and then increased. They also observed that as the substrate temperature increased, the light power attenuation rate increased while the thermal resistance decreased. From these observations, the researchers concluded that the variation in LED thermal resistance primarily stems from the differences in component materials and the thermal conductivity of the substrate.

PengFei Ji and colleagues *et al.* [18] conducted experiments to study the effective thermal resistance of LED packaging at different input currents. They utilized the formula effective thermal resistance = residual thermal resistance x (1 - optical efficiency) and adjusted the optical efficiency by varying the current to influence the effective thermal resistance. The results indicated that the effective thermal resistance of the 24milLED was higher than that of the 35milLED. Moreover, when the input current exceeded 100mA, the growth rate of the effective thermal resistance of the 24milLED was higher compared to the 35milLED.

In a study by C.T. Yang and colleagues *et al.* [19], the thermal resistance of multi-chip LED packaging using a first-level copper substrate was investigated. The researchers measured the thermal resistance for various thicknesses of copper substrates. It was observed that as the thickness of the copper substrate increased gradually up to 0.6mm, the copper thermal resistance decreased. However, beyond 0.6mm, the copper thermal resistance started to increase gradually. The smallest copper thermal resistance was achieved at a thickness of 0.6mm.

Kai-Shing Yang and colleagues *et al.* [20] focused on studying the heat transfer performance of high-power LED modules at different power levels using both experimental and numerical methods. The researchers found that reducing the substrate thickness or increasing the input power resulted in an increased importance of thermal diffusion resistance, leading to higher total thermal resistance and chip temperatures. Both the experimental and numerical analyses demonstrated that increasing the substrate thickness or utilizing a substrate material with high lateral thermal conductivity could reduce thermal diffusion resistance and effectively lower chip temperatures.

Young-Pil Kim and colleagues *et al.* [21] developed an LED packaging structure that combined the advantages of Chip-on-Board (COB) and a silicon substrate with a traditional metal-core printed circuit board (PCB). Experimental measurements were conducted to optimize chip heat dissipation and enhance reliability and lifespan. The incorporation of a silicon substrate contributed to cost reduction in LED production.

A packaging method called Chip-on-Metal (COM) was proposed by Seung-Ryol Maeng and colleagues *et al.* [22]. This method involved removing the insulation layer of the metal-core PCB typically used for Chip-on-Board (COB) chip packaging and directly packaging the chip on the metal layer of the PCB. The thermal characteristics of the chip were analyzed by experimentally measuring the junction temperature and thermal resistance of COM and COB packaging. The results demonstrated that COM packaging had a junction temperature that was 10°C lower than COB packaging, with temperature differences of 34.64°C and 45.28°C, respectively. The thermal resistance of COM packaging was approximately 1°C/W lower than COB packaging, with values of 0.7°C/W and 1.67°C/W, respectively. Additionally, a comparison of spectra, color coordinates, and changes in light speed between COM and COB packaging indicated that stable emission color improved light intensity and slowed down chip and packaging material degradation.

Kai-Shing Yang and colleagues *et al.* [23] conducted experimental research and theoretical analysis on the opto-thermal-electrical characteristics of high-power InGaN LED modules. The heat sink substrate consisted of two layers of materials, and three types of heat sink substrates were employed to investigate the relationship between chip temperature, thermal resistance, input power,

and luminous efficiency. The results revealed that thermal diffusion resistance accounted for the majority of the total substrate thermal resistance. The measured thermal resistance of the LED module increased as the input power increased. The measured luminous efficiency indicated that the electro-optical conversion efficiency was low, resulting in increased chip heat generation and elevated thermal resistance. Moreover, as the input power increased, the luminous efficiency of the LED decreased. The coupling effect of chip temperature, input power, and substrate thermal resistance contributed to efficiency degradation.

Based on the mentioned literature, extensive experimental research on LEDs has been carried out by both domestic and foreign experts and scholars. These studies involved measuring performance parameters, including junction temperature and luminous flux, at specific positions on the LED. However, it should be noted that experimental measurements only provide data for specific locations and not for all positions. Furthermore, experimental research is characterized by time-consuming processes, labor-intensive procedures, lengthy cycles, and high costs. As a result, many researchers have turned to numerical simulations as an alternative approach to studying LEDs.

### 3. Conclusion

This article examines the steady-heat-transfer, coupled-heat-transfer, and structural-thermal-stress-related performance of high-power LEDs and thoroughly studies their influencing factors. A comprehensive study for optimizing the performance of LEDs has been done. This is very important for enhancing the light power of LED chips and improving their heat dissipation performance.

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