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Thermal Characterization of Luxeon Star White LED on Plastic Heat Sink: Face and Rear Back Analysis via Digital Thermocouple and Thermal Imaging Camera

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Abstract

Effective thermal management is critical for the performance and lifetime of light-emitting diodes (LEDs), as high temperatures can damage performance, shorten lifespan, and diminish light output. The purpose of this study is to analyse and evaluate the thermal behaviour of the Luxeon Star White LED at both the top and back surfaces under different driver currents (100, 200, 250, and 300mA). The thermal behaviour was assessed using digital thermocouples and thermal imaging cameras, with temperature readings recorded over a 120-minute period. The findings show that the rear back surface consistently has lower temperature rises than the top surface, indicating more effective heat dissipation. At a driver current of 300 mA, the thermal resistance for the top surface was much higher (about 263.3°C/W) than the rear back surface (about 60°C/watt). Furthermore, running the LED at lower driver currents (100mA) resulted in the smallest temperature increase, showing negligible thermal stress. These findings highlight the need of optimizing heat management solutions for various LED surfaces. The study identifies the rear back surface as a vital region for improved cooling solutions and proposes that lower running currents can greatly reduce thermal stress, improving LED lifespan and performance. This study adds to our understanding of LED thermal behaviour, guiding the development of more efficient heat sinks and cooling methods to progress LED technology and applications.

Keywords: Luxeon Star White LED, Thermal Management, Digital Thermocouple, Thermal Imaging Camera, Heat Dissipation.

1. Introduction

Visible Light Communication (VLC) is an emerging field that leverages light-emitting diodes (LEDs) for wireless data transmission. VLC technology has gained considerable attention due to its potential to deliver high-speed data rates using the visible light spectrum, which is not only unregulated but also has a vast bandwidth compared to the radio frequency spectrum. One of the most crucial aspects of optimizing VLC systems lies in the efficient thermal management of LEDs. Effective thermal regulation not only improves the longevity of LEDs but also enhances their performance and stability in communication systems. Recent research highlights various thermal management strategies for LEDs used in high-power applications. For instance, studies have demonstrated that using nanofluids in heat pipes can significantly increase the thermal transfer rate compared to conventional cooling methods. For example, a diamond nanofluid with a

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5% concentration improved heat transfer by 18% over pure water, while other studies achieved even greater enhancements using different fluids and heat sink designs (Kim et al., 2024; Wang et al., 2023).

Innovative approaches like using cylindrical heat pipes and hybrid cooling systems with fins and fans have also shown promising results in reducing the operating temperature of LED systems. These techniques not only lower thermal resistance but also contribute to more uniform heat distribution, which is critical for maintaining the efficiency and durability of LED-based VLC systems (Jia Xuejiao et al., 2023). Additionally, advancements in LED packaging methods, such as Chip-on-Metal (COM) and modified lead frame designs have significantly reduced junction temperatures and improved thermal resistance. These improvements are vital for maintaining stable luminous output and enhancing the electro-optical efficiency of LEDs used in VLC applications (Kai-Shing Yang et al., 2023).

Recent studies have explored various thermal management strategies to improve heat dissipation in high-power LEDs, including the use of advanced heat sink designs, phase-change materials, and nanofluid-based cooling systems. These techniques aim to optimize the thermal resistance and lower the operating temperatures of LEDs, ultimately enhancing their efficiency and longevity (Yang & Tsai, 2023; Jia & Zhang, 2023). LEDs convert only a portion of electrical energy into visible light, with a significant amount dissipated as heat. This excess heat can lead to increased junction temperatures, affecting the LED's luminous efficacy, color stability, and overall lifespan. As LED systems continue to operate at higher power levels to meet the demand for brighter and more efficient lighting, efficient thermal management becomes essential to prevent thermal degradation and ensure reliable operation (Narendran & Gu, 2005; Mao & Chen, 2012).

The Luxeon Star White LED, known for its high brightness and energy efficiency, is widely used in both general lighting and VLC applications. However, its performance is highly dependent on efficient thermal management to maintain low junction temperatures under varying operating conditions. Previous research indicates that improving the heat dissipation at the rear surface of the LED, compared to the top surface, can significantly reduce thermal stress and increase the operational lifetime of the device (Kim et al., 2024).

This study focuses on characterizing the thermal behavior of the Luxeon Star White LED mounted on a plastic heat sink by analyzing temperature distribution at both the top and rear surfaces. The aim is to understand how different driver currents affect the heat dissipation and to identify strategies for optimizing thermal management to enhance LED performance and reliability.

2. Methodology

The thermal behavior of the Luxeon star white LED was studied using digital thermocouples and thermal imaging camera in plate 1: The LED was mounted on a plastic heat sink, and temperature measurement were taken on both the top and rear back surfaces at four different driver currents (100mA, 200mA, 250mA and 300mA) over a 120-minute period. Data collection occurred every 5 minutes, and thermal resistance was calculated for each current setting to assess heat dissipation efficiency.

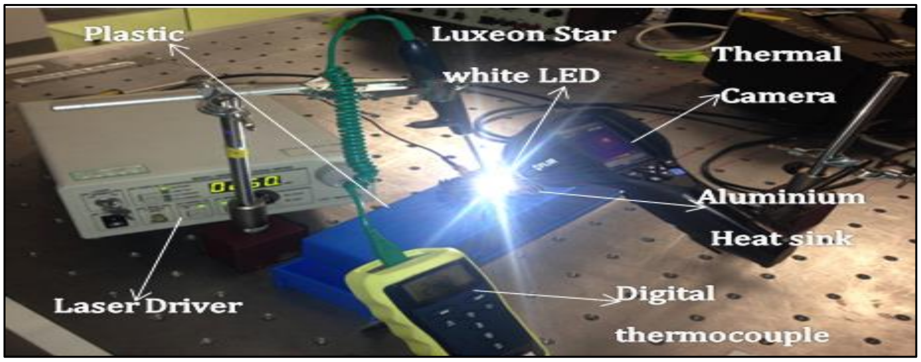


Plate 1: Experimental setup for the Luxeon Star white LED

The ambient temperature ($T_{ambient}$) is 25°C, the thermal(R_{th}) using steady-state temperature formula;

For 300mA (Top surface), Thermocouple

$$\Delta T_{top} = 48.7 - 25 = 23.7°C \quad (1)$$

$$Q = I^2 R = (0.3)^2 \times R = 0.09 \times R$$

$$R_{th,top} = \frac{\Delta T_{top}}{Q} = \frac{23.7}{0.09} = 263.3°C\ /W \quad (2)$$

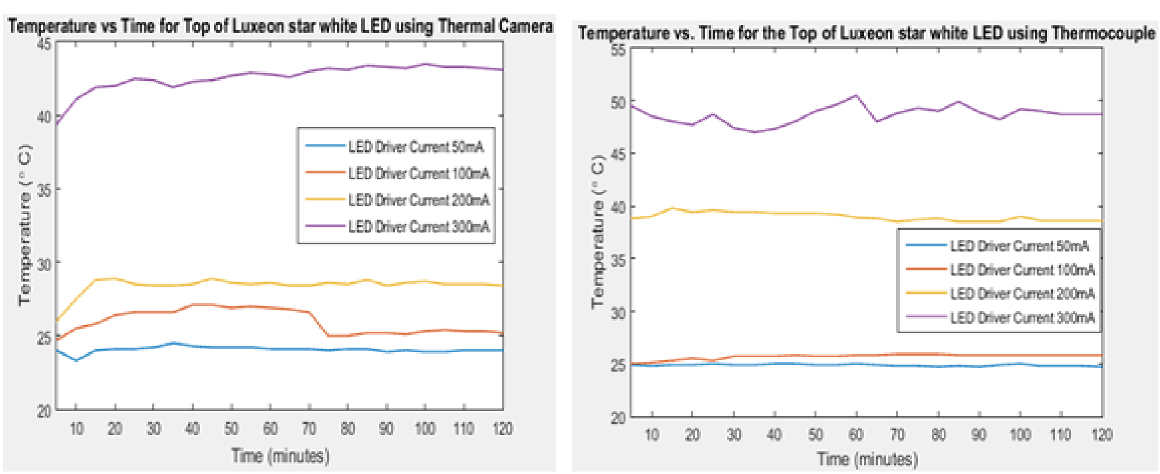
For 300mA (Rear Back surface), Thermocouple

$$\Delta T_{rear} = 30.4 - 25 = 5.4°C$$

$$Q = 0.09 \times R$$

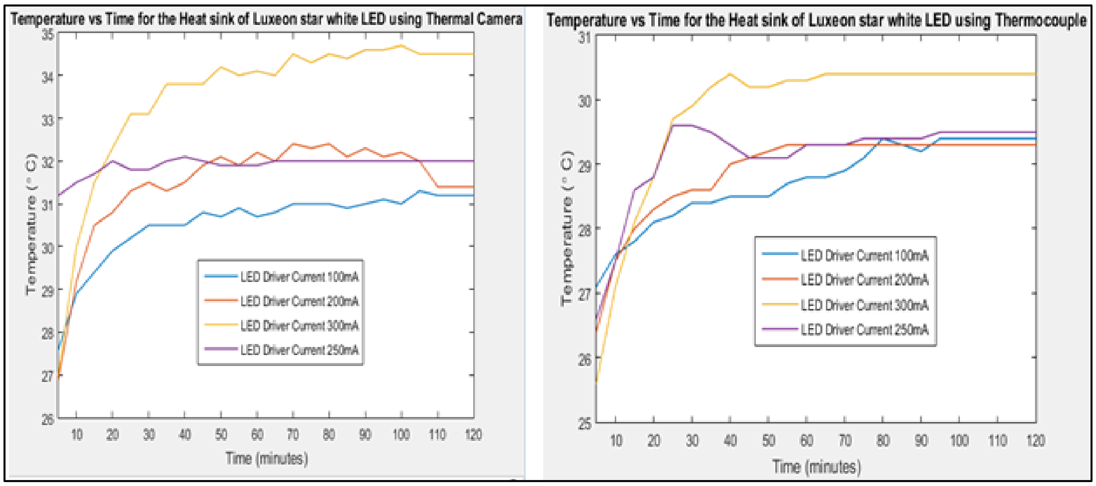
$$R_{th,rear} = \frac{\Delta T_{rear}}{Q} = \frac{5.4}{0.09} = 60°C\ /W \quad (3)$$

3. Results and Discussion



(a) (b)

Fig 1: a and b Temperature vs Time for the Top of Luxoen Star white LED both Thermal Imaging Camera and Digital thermocouple



(a) (b)

Fig 2: a and b Temperature vs Time for the Rear Back (Heat Sink) of Luxoen Star white LED both Thermal Imaging Camera and Digital thermocouple

3.1 Top Surface Temperature Analysis

Graphs of 100 to 300mA in Fig 1: show the temperature progression at the top surface for 300mA, 200mA, and 100mA, respectively. The temperature increases rapidly initially and stabilizes over time. The graph compares the temperatures for all currents, highlighting the significant rise in temperature at higher currents.

3.2 Rear Back Surface Temperature Analysis

Graphs of 100 to 300mA in Fig 2: depict the temperature rise at the rear back surface for 300mA, 200mA, and 100mA, respectively. Similar to the top surface, the temperature stabilizes after a certain period. Graph 8 compares the temperatures for all currents at the rear back surface, showing more efficient heat dissipation compared to the top surface.

3.3 Comparison of Top and Rear Back Surfaces

The rear back surface consistently exhibited lower temperature rises compared to the top surface, indicating superior heat dissipation capabilities. At a driver current of 300mA, the thermal resistance for the top surface was significantly higher (approximately 263.3°C/W) compared to the rear back surface (approximately 60°C/W). Lower driver currents (100mA) resulted in the least temperature rise and heat dissipation, suggesting minimal thermal stress on the LED.

4. Conclusion

The study found that the rear back surface of the Luxeon Star White LED dissipates heat more efficiently than the top surface, particularly at higher driver currents, specifically; the thermal resistance for the top surface was significantly higher (approximately 263.3°C/W) compared to the rear back surface (approximately 60°C/W) at a driver current of 300mA. The lowest driver current (100mA) resulted in minimal thermal stress, indicating that lower currents are optimal for extending the LEDs lifespan and maintaining its performance.

These findings contribute to the understanding of LED thermal behavior, highlighting the rear back surface as a key area for enhanced cooling solutions. The results inform the design of more effective heat sinks and cooling mechanisms, advancing LED technology and improving its applications in various lighting solutions.

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