Effect of ambient temperature and heating time on high-power LED

D S Peng\textsuperscript{1,*} and K L Liu\textsuperscript{1}

\textsuperscript{1}College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen, China

E-mail: sbpengds@szu.edu.cn

Abstract. LED is widely used in various fields as a new style of light sources. Today the efficiency of LED electro-optical conversion is only 20%, and the rest of energy release in the form of heat, which is generating higher junction temperature. The junction temperature rise will cause serious thermal problems and affect the performance of the LED. In this paper, we mainly focus on the research of the thermal problem of the high-power LED. The result shows that the junction temperature and thermal resistance of the R and G-based LEDs increase with the increase of the ambient temperature and the heating time. This leads to an increase in operating current, ambient temperature, and usage time during operation of the high-power LED, which causes the low luminous efficiency of the LED, thereby increasing the amount of heat generated, which easily causes aging of the device and permanent light decay. Therefore, reducing the thermal resistance and junction temperature in the previous LED design will greatly help the thermal and optical improvement of the LED.

1. Introduction

Because LEDs glow at the same time accompanied by the generation of heat, the PN junction temperature of device will be higher than the outside environment temperature \cite{1,2}. At present, LED applications are increasing, and the demand for LED is gradually becoming bigger. In addition to high power, people are also looking for higher luminous efficiency, and new applications need to avoid excessive heat generation. The main factors affecting the efficiency of luminescence, in addition to the material characteristics of the LED itself, also include the operating temperature \cite{3-5}.

The increase of LED junction temperature will not only cause the decrease of light pass and luminous efficiency, but also affect the radiation wavelength, color temperature, life and so on. The increase in junction temperature increases the probability of compounding between the excited sons, so the radiation wavelength will shift red and the wavelength will be longer. In addition, the increase in temperature allows the LED color temperature to drift, and it can make the luminous intensity decrease \cite{6-10}.

At present, the domestic measurement method of LED temperature and thermal resistance has not yet formed a more mature unified standard. The existing measurement methods mainly include spectroscopy, infrared micro imaging, blue-white ratio, pin temperature and positive voltage. In this paper, the positive voltage method is used to test and analyze it. This is a non-destructive measurement method with high measurement accuracy, high sensitivity and fast measure speed. It will greatly improve the thermal and optical properties of LED to reduce the thermal resistance and junction temperature in the early LED design.
2. Experiment Theory
Input power is the only source of LED heat generated, which is converted into radiant light partly and eventually into heat, resulting in an increase in the temperature of the PN junction. Therefore, to reduce the increase of LED knot temperature, on the one hand, it can maximize the device's photoelectronic conversion efficiency, so that more input power conversion to light can be fully utilized, on the other hand, it can improve the device's thermal emission capacity, so that the heat generated by various means released to the surrounding environment.

Thermal resistance is an essential parameter for studying LED thermal characteristics. When the thermal balance is reached, the ratio of the temperature difference between the two specified points or areas along the thermal conduction path and the thermal power consumption generated on the thermal conduction path is thermal resistance. The formula is as follows:

\[ R_{th} = \frac{T_j - T_a}{P_D} \]  

(1)

Where, \( T_j \) and \( T_a \) represent the temperature of the LED device PN junction and the ambient temperature respectively, \( P_D \) is the thermal power consumption of the LED device. Based on the simulation, the junction temperature under the same conditions is higher with the increase of the thermal resistance. Excessive junction temperature has a negative effect on the luminous efficiency and performance stability of LED devices.

Based on the temperature coefficient \( K \), by heating the current to the set ambient temperature \( (T_a) \), the voltage value \( (V_f) \) is obtained, and then the test current is quickly switched, the output voltage value \( (V_{fa}) \) is obtained. The junction temperature of the LED can be obtained. The formula is as follows:

\[ T_j = \frac{V_f - V_{fa}}{K} + T_a \]  

(2)

The experimental process is shown in figure 1.

In this paper, the test samples used in this experiment are red high-power 1W LED with the luminous flux 40-50lm and green high-power 1W LED with the luminous flux 60-70lm. The internal structure includes LED chip, metal base, silver layer, and thermal substrate.

3. Results and Discussion
Ambient temperature and heating time have a great influence on LED junction temperature and thermal resistance. The junction temperature and thermal resistance of the red and green power LEDs vary with the ambient temperature, as shown in figures 2 and 3.
Based on the figure 2 and figure 3, with the increase of ambient temperature, the junction temperature and thermal resistance of red-light power LED and green-light power LED will gradually increase. This is due to the increase of ambient temperature, the lattice mismatch between the various extension layers within the LED chip and the density of defects within the material will also increase, the rapid growth of defects, reproduction and thus spread to the luminescence zone, it will make the generation of a large number of deep energy stage, resulting in an increase in the non-radiation composite rate and light efficiency reduction. The heat energy increase will result in LED temperature and thermal resistance increase.

Increased ambient temperatures can cause the packaging materials of LED devices, such as epoxy resins, silver glues, and brackets, to vary in material performance. The heating of epoxy resin will lead to material expansion, structural changes in the device housing, and changes in the optical properties of LED devices, which will eventually lead to a decrease in optical efficiency, the conversion of electrical power to thermal power. It can result in the increase of the junction temperature and thermal resistance.
of LEDs. At the same ambient temperature, the junction temperature and thermal resistance of the green LED are larger than those of the red LED, because the defect density of InGaN material in green LED is higher than that of AlGaInP material in red LED. Lower photoelectronic efficiency will generate more thermal power, junction temperature and thermal resistance in the green LED. It can be seen that the increase of ambient temperature has a great influence on LED thermal resistance.

**Figure 4.** Relationship between Junction temperature of power LED and heating time.

**Figure 5.** Relationship between thermal resistance of power LED and heating time.

The junction temperature and thermal resistance of the red and green power LEDs vary with the heating time, as shown in figures 4 and 5.

Based on figure 4 and 5, the junction temperature and thermal resistance of red and green LEDs will rise slowly with the increase of heating time, and eventually stabilize. This is due to the increase of heating time, the lattice mismatch in the LED chip and the density of material defects will increase with the increase of heating time, defects will spread to the light-emitting area of the P-N junction. It will result in an increase in non-radiation compounding inside the material, generating heat, so that the junction temperature and thermal resistance increase. With the increase of heating time, the defect
density will stabilize, resulting in a more and more slow change of the junction temperature and thermal resistance, and finally stabilize.

In the same conditions, the junction temperature and thermal resistance of R-based LEDs are lower than those of G-based LEDs. The InGaN material defects in green LED are higher than AlGaInP material defects in red LED, with the temperature and operating current increase, the material defect density increased, resulting in non-radiation compound increase, thermal power increase, so the thermal performance of green light power LED will be worse than that of red light power LED.

4. Conclusions
As the ambient temperature increases, the junction temperature and thermal resistance of the red and green high-power LEDs increase. With the increase of heating time, the junction temperature and thermal resistance of red and green high-power LEDs will increase and eventually stabilize. The increase of junction temperature and thermal resistance is also accompanied by the decrease of LED optical power, the aging of the device and permanent light decay, so it is particularly important to reduce the junction temperature and thermal resistance of high-power LEDs. This is a non-destructive measurement method with high measurement accuracy, high sensitivity and fast measure speed. It will greatly improve the thermal and optical properties of LED to reduce the thermal resistance and junction temperature in the early LED design.

Acknowledgements
The authors would like to acknowledge the funding support by the Rising Industry Development Foundation of Shenzhen, China (Grant No. JCYJ20180305124822272).

References
[1] Pekur D V, Sorokin V M and Nikolaenko Y E 2020 Thermal characteristics of a compact LED luminaire with a cooling system based on heat pipes Therm. Sci. Eng. Prog. 18 100549
[2] Sosoi G, Vizitiu RS, Burlacu A and Galatanu CD 2019 A heat pipe cooler for high power LED’s cooling in harsh conditions Procedia Manuf. 32 513–19
[3] Lin X, MO S, Mo B, Jia L, Chen Y and Z Cheng 2020 Thermal management of high-power LED based on thermoelectric cooler and nanofluid-cooled microchannel heat sink Appl. Therm. Eng 172 115165
[4] Feng S, Shi M, Yan H, Sun S, Li F and Lu T J 2018 Natural convection in a cross-fin heat sink. Appl. Therm. Eng 132 30–7
[5] Tang Y, Lin L, Zhang S, Zeng J, Tang K, Chen G and Yuan W 2017 Thermal management of high-power LEDs based on integrated heat sink with vapor chamber. Energy Convers. Manage 151 1-10
[6] Shin D H, Baek S H, Ko H S 2016 Development of heat sink with ionic wind for LED cooling. Int. J. Heat Mass Transf 93 516–28
[7] Guerra L E P, Sehgal S, Valle C U G and Alvarado B R 2019 Fractal channel manifolds for microjet liquid-cooled heat sinks. Int. J. Heat Mass Transf 138 257–66
[8] Seo J H and Lee M Y 2018 Illuminance and heat transfer characteristics of high power LED cooling system with heat sink filled with ferrofluid Appl. Therm. Eng 143 438–49
[9] Dong S, Feng S, Qiao Y and Deng B 2015 Thermal investigation of LED array with multiple packages based on the superposition method Microelectron. J 46 632-36
[10] Eler G, Kandaswamy S V and Liu E 2015 Analysis of solder joint reliability of high power LEDs by transient thermal testing and transient finite element simulations Microelectron. J 46 1230-8