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Thermal management for high-power photonic crystal light emitting diodes

Yuanyuan Chen, Bin Sun, Tianhe Ma, Xiaohan Sun *

National Research Center for Optical Sensing/Communications and Networking, Lab of Photonics and Optical Communications, Southeast University, Nanjing 210096, China

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ABSTRACT

An effective heat dissipation structure is a crucial element for stable thermal management in ensuring thermal stability of high power photonic crystal light emitting diodes (PC-LEDs). New integrated structure for effective thermal management is put forward for high power PC-LEDs to reduce the thermal resistance between the chip and heat dissipation device, which can be composed by the heat pipes or an active heat dissipation device. Based on the thermal resistances analyzed, 3D thermal distributions for the device CSM360 with the nominal electric power of 80 W are simulated and analyzed by using of ANSYS. Compared with the general metal fins model, the heat pipes integrated model improves the heat dissipation efficiency of CSM360 by 36.61%, while the active heat dissipation device integrated model improves the heat dissipation efficiency by 60.2% at the temperature of 50 °C on the cold end of the device. The results show that the integrated structure can obtain a significant improvement in thermal management and achieve a reduction in temperature in the working status of CSM360. Heat dissipation experiments are also conducted, and the values of temperature distributions are validated to be coincident with those from simulations.

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1. Introduction

High power photonic crystal LEDs (PC-LEDs) have a great potential to become a new illumination source for general lighting applications due to their high efficiency and long service life [1]. To achieve higher light output performance, it is necessary to drive PC-LEDs to a high current density level, which remarkably generates a large portion of heat and increases the junction temperature of the device due to the Joule heating at the P–N junction [2]. The heat will increase the junction temperature, cause negative effects on carrier mobility, energy band width and affect the stable operation of PC-LEDs [3]. Enhancements in the efficiency and stable working of PC-LEDs are exciting the interesting works of research and development to expand their application to high power areas, and effective thermal management of PC-LEDs making use of efficient heat dissipation structures with lower thermal resistance is of critical importance [4]. In conventional heat dissipation structures, the generated heat is dissipated through the path from substrate to connecting material and then to heat sink. Metal heat sinks and heat pipes and fans are the most commonly used heat dissipation devices to ensure the temperature of the PC-LEDs staying at a low level which is essential for efficient light production and long operational life time [5]. There have been several studies on the thermal distribution of different heat dissipations models of LEDs device, such as the silicon based micro channel coolers [6], channel heat sink with fan [7] and heat pipes cooling [8]. The connecting materials between the chip and the heat dissipation devices are always screws or heat conduct silicones which will bring new thermal contact resistances [9,10]. Due to the poor thermal conductivities of the connecting materials, the heat dissipation efficiencies are low and PC-LEDs always suffer from power saturation phenomenon. There also have been many researches done to effectively reduce the thermal resistance of the high power LEDs, such as flip chip method [11], gold evaporation or gold wire bond [12] and reflow or thermionic flip chip bonding [13]. However, there are seldom researches trying to further eliminate the connecting resistance between PC-LEDs and the heat dissipation devices or comparing heat dissipation performance of different heat dissipation models.

In this paper, we propose a thermal management to ensure a safe working status for high power PC-LEDs. New integrated structure for effective thermal management is put forward for high power PC-LEDs to reduce the thermal resistance between the chip and heat dissipation device, which consist of heat pipes and active heat dissipation device, respectively. The two models can eliminate the thermal resistance between PC-LEDs and heat dissipation devices, and improve the heat dissipation efficiency of PC-LEDs. We also discuss different occasions for the two integrated models according to their features respectively and conduct some heat dissipation experiments to validate the simulation results.

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* Corresponding author. Tel.: +86 25 8379 3686.
E-mail address: xhsun@seu.edu.cn (X. Sun).

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2. Theoretical analyses

2.1. Thermal management scheme

An effective thermal management for PC-LEDs is proposed and the scheme is shown in Fig. 1. It consists three major functional blocks. (1) The driver block, which supplies a high driving current for PC-LEDs [14]. (2) PC-LEDs block, in which the thermistor is integrated on PC-LEDs and different heat dissipation devices and structures should used according to different applications. (3) CPU controller block, which employs the resistance of thermistor as the control signal and controls the driver and heat dissipation devices. In a working status, when the temperature of PC-LEDs changes slightly, CPU adjusts the voltage of heat dissipation devices to meet different cooling demands. If the temperature of PC-LEDs rises uncontrollably in unexpected occasions (a sudden failure working of heat dissipation devices, etc.), the resistance mutation of thermistor will stimulate CPU to control the driver to decrease the driving current or even shut off PC-LEDs. So, this thermal management method can ensure a stable working status for PC-LEDs during the operation of PC-LEDs, in which the heat dissipation devices and the way CPU works are two crucial elements. In this paper, we mainly discuss the structure for heat dissipation devices.

2.2. Theoretical modeling

Heat transfer is the energy transmission from one region to another due to the temperature difference between the structure and ambient temperature. The transmission of heat from a high-temperature region to a low-temperature one is mainly by three methods: conduction, convection, and radiation [15]. As the heat dissipated by radiation consists of only a small part of all heat [16], we neglect heat radiation and only take heat convection and conduction into consideration in this paper. The structure of PC-LEDs is shown in Fig. 2. The heat is dissipated from LED chip, copper substrate, connecting material to the heat dissipation devices. When LEDs get turned on, the temperature begins to increase at first, and then the temperature of LEDs and environment reaches a balanced thermal steady state with time going on. It is until the thermal steady state that the temperature of LEDs reaches the max value and then become almost stable in the following time. So heat dissipation analysis of LEDs considers the steady state [17]. The steady state heat transfer governing equation for PC-LEDs is

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+Q=0 \tag{1}$$

where k (W/m K) is thermal conductivity of the materials, Q (W/m^3) is the heat generation rate, T (°C) is the temperature in steady state condition. Thermal boundary conditions can be expressed as follows:

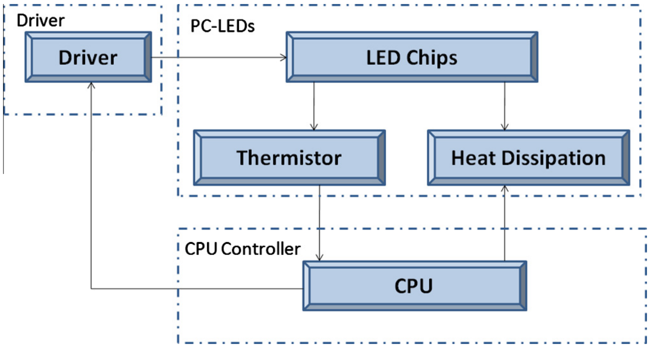

Fig. 1. The scheme of thermal management for high power PC-LEDs.

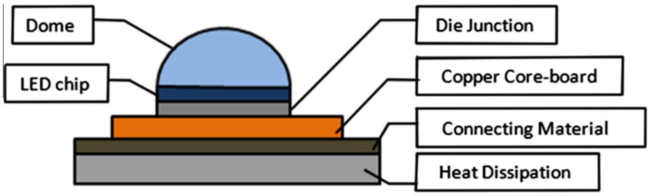

Fig. 2. The schematic diagram of PC-LEDs.

$$T|_{\Gamma}=T_0 \tag{2}$$

$$-k\frac{\partial T}{\partial n}\bigg|_{\Gamma}=q \tag{3}$$

$$-k\frac{\partial T}{\partial n}\bigg|_{\Gamma}=h(T_{\omega}-T_f) \tag{4}$$

where Γ is the wall surface of one component, T_0 is the uniform temperature, T_{ω} is the surface temperature, and T_f is the surrounding temperature, n is the normal direction of the surface, h (W/m^2 K) is the convection heat transfer coefficient. Combining these equations, unique numerical solution of Eq. (1) can be determined and corresponding temperature distribution thus can be obtained.

2.3. Thermal resistance analyses

Thermal resistance is a measure of a material's ability to resist heat transfer. The higher it is, the lower the heat transfer ability will be. For high power PC-LEDs, a little decrease of thermal resistances will play a vital role in decreasing the junction temperature [18].

The high power PC-LEDs CSM360 from luminous Co. Ltd. is chosen as the research object and the model is built by Ansys. CSM360 has four P–N junctions connected in series which integrated on the surface of copper substrate and it has a high power of 80 W. The geometry property of CSM360 is shown in Fig. 3 (a and the distribution of thermal resistance is shown in Fig. 3(b), $R_{\text{j-bs}}$ is the thermal resistance from the P–N junction to the copper, $R_{\text{b-hs}}$ is the thermal resistance from the copper to the heat dissipation devices and $R_{\text{hs-amb}}$ is the thermal resistance from heat dissipation devices to the air. The three thermal resistances compromise the thermal resistance from the P–N junction to the air of CSM360 and their typical values are shown in Table 1.

The thermal resistance of a single semiconductor component is generally defined as

$$R_{\text{th},i}=\frac{T_{i+1}-T_i}{P_d} \tag{5}$$

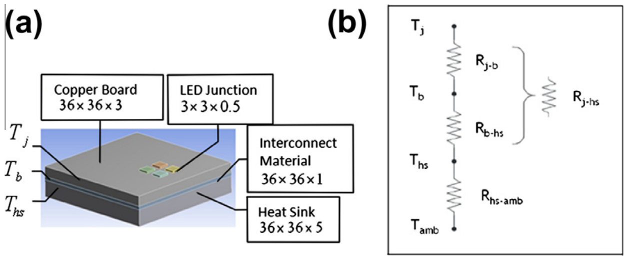

Fig. 3. (a) The model of CSM360 (dimension in millimeters). (b) Thermal resistance distribution of CSM360.

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