Applied Thermal Engineering xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

A novel automated heat-pipe cooling device for high-power LEDs

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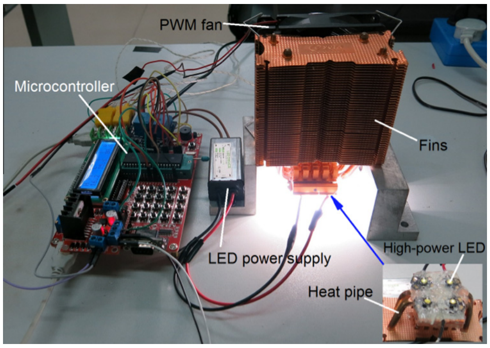
HIGHLIGHTS

- An automatic cooling device was firstly integrated with microcontroller, heat pipe and fan.
- Substrate temperature of high-power LEDs can be controlled automatically and be protected safely.
- LED junction temperature can be maintained at a suitable range.
- Total power consumption is less than 1.58 W.
- It is a very promising tool for the heat dissipation of high-power LEDs.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 August 2016
Revised 29 September 2016
Accepted 8 October 2016
Available online xxxx

Keywords:
High-power LEDs
Heat pipe
Automatic cooling system
Numerical simulation

ABSTRACT

In order to develop the thermal management of high-power LEDs, an automatic cooling device was firstly integrated with a microcontroller, heat pipes and fan. According to the experimental results, it was found that the substrate temperature of the high-power LEDs could be controlled automatically, and it could be kept in a relative low range to protect the LEDs, which contributes a better performance and longer lifetime of LED. A numerical model of the cooling system was established and its effectiveness was verified by experimental results. The simulation results show that the LED junction temperature can be maintained at a suitable range. Thus, the thermal resistances R_{sa} (from the heat sink to the ambient) and R_{ja} (from the LED chip to the ambient) of the cooling system are 0.373 °C/W and 5.953 °C/W at 12 W, respectively. In addition, increasing the number of heat pipes & cooling fins is an effective method to improve heat transfer of the cooling system. The proposed cooling system, whose total power consumption is less than 1.58 W, is a very promising tool for the heat dissipation of high-power LEDs.

1. Introduction

Light emitting diodes (LEDs) have gained popularity in the application of street lamps, advertising displays, automotive headlights and traffic lights. In contrast with fluorescent and incandescent lighting [1–4], LEDs' ascending applications can be ascribed to their merits, including of long lifetime, high reliability and low energy consumption, short response time, variable color and environmental benign effect. Even though high-power LEDs have a high energy efficiency of around 15–25% from power to light under the current level of technology contrasted with 10% in traditional lighting, there is still more than around 80% of the electric power consumed by LED devices as heat dissipation which will result in high chip junction temperature [5,6]. The temperature of chip's junction should be kept at an appropriate range (normally below 120 °C) to ensure its performance and service life. In some applications, the need for LED illumination can reach 3000 lm/lamp or even more, which gives rise to the concerns of thermal issues in the mass production and wide application of high power

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http://dx.doi.org/10.1016/j.applthermaleng.2016.10.041
1359-4311/

LEDs. Various researches have revealed that high junction temperature accelerates the degradation of optical efficiency, drifts the luminescence wavelength and shortens the device life [7,8]. Heat management is thus a prior issue both the development and application of high-power LEDs.

Various types of cooling system, including active, passive and hybrid cooling devices have been developed for high-power LEDs applications in recent years. Hsieh et al. [9] proposed a microspray-based cooling system for the thermal management of high-power LEDs. The results demonstrated that spray cooling was an efficient way to remove high heat flux from high power LEDs. Liu et al. [10] compared three different microjet structures of cooling system used in high power LEDs based on numerical simulations. Sufian et al. [11] used dual piezoelectric fans to cool multi-LED packages based on experimental and numerical analyses considering both natural and forced convection conditions. The results showed that the dual fans enhanced the heat transfer performance approximately by 1.28 times of the single fan. Li et al. [12,13] designed a cooling system with thermoelectric cooler (TEC) to improve the heat dissipation of high-power LEDs, which verified that the maximum LED power cooled by the system was 106.7 W. Deng and Liu [14] proposed an active liquid metal cooling system for high power LEDs, and the experiments and theoretical analysis indicated that liquid metal cooling was a powerful way for heat dissipation of high power LEDs. Thermal performance of an active liquid cooling solution for bright LEDs automotive headlights was investigated based on experiment and simulation [15]. Lu et al. [16,17] developed a flat and loop heat pipe to improve heat dissipation for high power LED. Hsieh et al. [18] presented a novel flat heat pipe with a coronary-stent-like wick structure. The performance of the structure was measured under different operating condition. The junction temperature and thermal resistance of LED array with heat pipes were calculated based on thermal transient method [19]. Thermal characteristics of power LED cooled by water flow was analyzed through experimental study [20]. Yang et al. [21] designed a newly flat polymer heat pipe, the efficiency and heat transfer characteristics of which was investigated by a fabricated laboratory model. Yu et al. [22] investigated the radial heat sink for dissipating heat adapted to the circular LED light, using multi-objective optimizations based on numerical simulations. Among the traditional cooling technologies, metal fin heat sinks have high reliability, but their cooling efficiency is insufficient with natural convection. The heat pipe, which consists of an evaporator, a condenser and a thermal insulator, with the advantages of high conductive coefficient, low thermal resistance and small volume, is an alternative efficient cooling method [23]. Currently, the heat pipe integrated assemblies is still the typical method due to its high reliability and low cost [24]. Therefore, two-phase cooling devices with various liquid coolants are developed for thermal management of high power LEDs to achieve the more cost-effective and more reliable performance [25–28]. In order to optimize the heat dissipating performance of a heat pipe radiator, a parametric study was used to optimize parameters of radiator, such as orientation [29], coolant [30], fin shape and intervals [31], material of heat sink [32], the ventilation of fan [33], etc. More remarkable, active cooling is necessary and even crucial important for thermal management of high power LEDs. But the drawbacks of using active cooling are obvious. Once the fan is broken down, the whole lighting apparatus will burn out due to the insufficient heat removal. It is aggravated when the unpredictable and severe working conditions for outdoor are encountered. Therefore, the heat pipe radiator with self-adjust or auto-control is necessary to achieve the requirement of highly reliable operation of LEDs.

In order to achieve the heat dissipation requirement of high power LEDs, this work was undertaken to examine the performance of a novel automatic cooling device which consists of heat pipes, a microcontroller and fan. According to the theory of heat transfer, the thermal resistance of the cooling system was analyzed. In addition, a numerical model was developed by using the ANSYS Icepak 14.5 software and comprehensively validated with experimental results. The model was employed for steady state analysis of the thermal performance of the cooling system. The effects of heat pipes, cooling fins as well as heat plate are discussed using the established model.

2. Novel automatic cooling device and experiment

An automatic cooling device with heat pipes for high power LEDs is developed, as shown in Fig. 1. The cooling devices consist of a microcontroller, PWM fan, heat pipes and cooling fins. The light source is composed of four high-power LEDs, which come from Shenzhen Quantum Optoelectronic Co., Ltd. According to the product instructions, this type of LED chip can work within the temperature range −40 to 130 °C, and the critical quantity of junction temperature is less than 120 °C. Moreover, the diameter of substrate is 20 mm; the typical CCT is 3000 K; the rated power is 3 W. Table 1 illustrates the detail of photoelectric parameters of high power LED module. The LEDs are connected together in series, and a constant current is supplied to each LED using a special power supply of high power LED. Four array LED modules are assembled on the evaporator side of the heat pipe, which is embedded into a metal heat plate used as heat sink. The diameter of the heat pipe is 6 mm and the length of characteristic dimension is 128 mm. The fan is the four-wire speed fan with pulse width modulation (PWM), whose model is D07R-12T3U with more than 100,000 h lifetime. The dimension of WPM fan is $80 * 80 * 25$ mm. The rated voltage and current are DC 12 V and 0.12 A, respectively. The fan speed is 0–2600 RPM (speed adjustable), and the maximum ventilation is 65 CFM. Both the substrate temperature of LED and ambient temperature are measured by K-type thermocouples 1 & 2, respectively. The measurement error is about 1 °C at the temperature range from −30 °C to 150 °C.

2.1. Control system of the cooling device

In order to meet the need of automatic control and device protection, a compact control system, integrated microcontroller, LCD display, A/D converter and digital temperature sensor, has been presented in Fig. 2. The key component of control system is a single chip computer (MCS-52), which comprises central processing unit (CPU), random access memory (RAM), input/output (I/O) and interrupt logic in one package. The selected 8052 architecture microcontroller has a high-performance microprocessor (CMOS 8

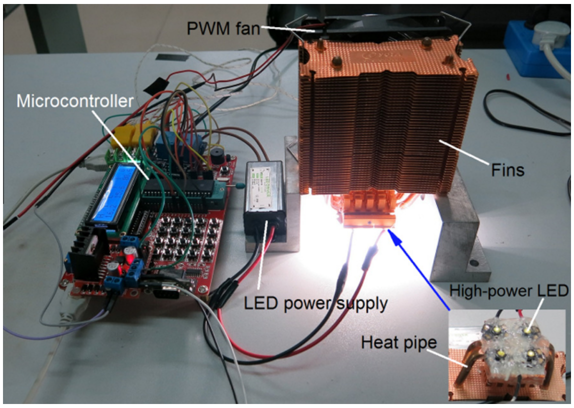

Fig. 1. The automatic heat pipe cooling device.

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Table 1
The parameters of high-power LED.

LED parameter	Ratings	Units
Power dissipation	3	W
Forward current	800	mA
Voltage	3–3.6	V

bit) with 8 K bytes flash which is a programmable and erasable read only memory. The microcontroller provides a high flexibility and low cost solution for the control system. Real-time temperatures on substrate surface measured by K-type thermocouple 1 & 2 are converted to digital signal, by using MAX6675 A/D Converter. This digital signal is used to control the whole cooling system. Ambient temperature is monitored by a DS18B20 sensor. If the temperature difference between the thermocouple and the DS18B20 sensor is greater than a set value (2 °C in this research) or the substrate temperature reaches up to the set temperature (30 °C), the PWM fan starts to work and will not stop until the temperature difference or the substrate temperature decreases below the set point. When the temperature difference between the K-type thermocouple and the DS18b20 sensor reaches up to 2 °C, 4 °C, 5 °C, and 6 °C respectively (the temperature difference can be assigned different values according to practical conditions), the PWM fan starts to work with different speeds. The greater the temperature difference is, the faster the rotational speed of the fan is. The speed of fan is controlled by pulse signal, and signal processing is completed by a L298N driving circuit. To ensure the safe operation of high power LEDs, when the substrate temperature of LEDs reaches to the critical value (according to our previous research [33], the critical value was set 40 °C in this research), the microcontroller will cut off the power LEDs and sound the alarm. Moreover, if the microcontroller receives no response within five minutes, the power of fan and microcontroller will be cut off automatically. To observe the operation of the cooling device conveniently, the real-time temperatures of thermocouple 1 and 2 as well as the rank of fan speed are shown in a display (LCD 1602, which is a dot matrix LCD module). All the modules are fixed on the PCB board, which is an internal structure that holds the control information for a connection. The automatic cooling system can save energy and provide security protection for high power LEDs during the normal operation.

2.2. The principle of control system

The software of control system is programmed in C++ programming language based on modular programming principle, which makes the program readable, modifiable and relatively independent and also reduces difficulties and costs of system integration. According to the design criteria, the procedure is divided into eight modules including the main function module, thermocouple temperature acquisition module, 1602 LCD display module, PID control algorithm module, fan speed control module, keyboard communication module, environment temperature acquisition module and temperature limit alarm module. Communication between the MAX6675 A/D convertor and the MCS-52 microcontroller is connected through non-isolated SPI-compatible serial interfaces. A complete read with the serial interface requires 16 clock cycles. The first bit (D15) is a dummy sign bit and is always zero. Bits D14–D3 contain the converted temperature in the order of MSB to LSB. Bit D2 is normally low, but it goes high when the thermocouple input is open. D1 is low to provide a device ID for the MAX6675 and bit D0 is three-state. The communication of the temperature sensor (DS18B20) is based on Monobus LIN Protocol. Since the communication of DS18B20 chip uses a single BUS, the timing signal is very important. The resolution of DS18B20 is 0.0625, and the relationship between temperature 'y' and data 'x' is as follows:

$$y = (x \times 0.0625) \times 10 + 0.5 \qquad (1)$$

The PID (Proportional Integral Derivative) algorithm is used in the control system. It is a robust, easily understood and the most popular feedback algorithm used in the process industries [34].

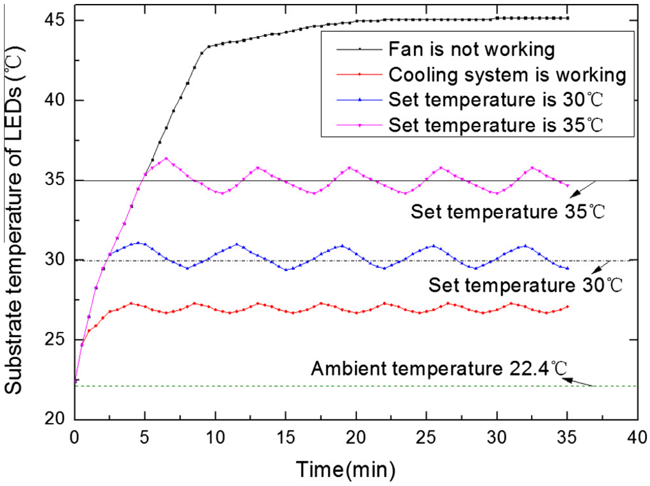

Fig. 3. Experimental results under different conditions (22.4 °C ambient temperature).

2.3. Certification program and cooling performance

In order to ensure the cooling system work properly, the functionality and reliability of software program should be confirmed by the experimental approach. There are three functions and sta-

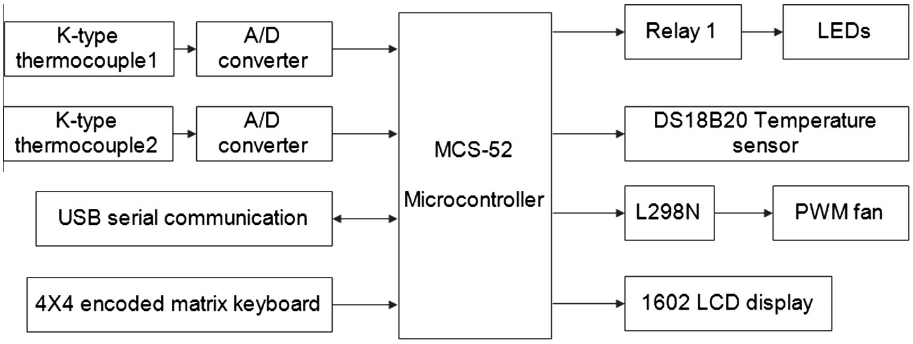

Fig. 2. Schematic diagram of control system.

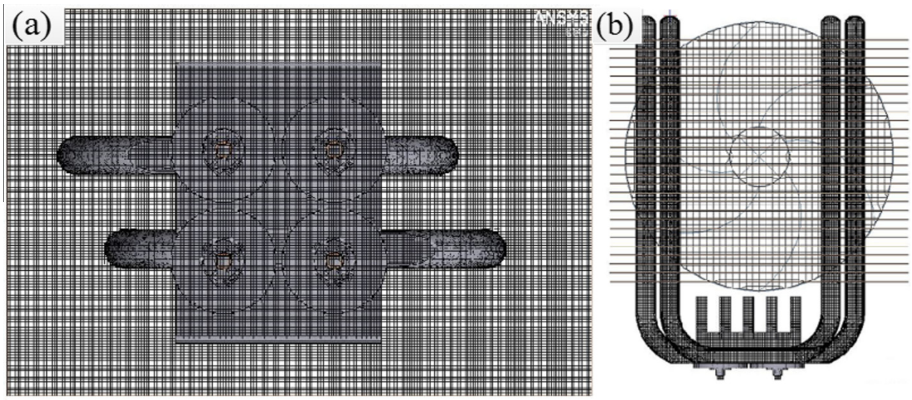

Fig. 4. Finite element mesh model of heat pipe cooler: (a) is bottom-view, and (b) is front-view.

Table 2
Comparison of steady state temperature between experiment and simulation.

	Experimental data		Numerical result	
	Thermocouple 1	Thermocouple 2	Monitor point 1	Monitor point 2
7.6CFM	28.6 °C	28.3 °C	28.03 °C	27.78 °C
15.25 CFM	26.9 °C	26.5 °C	26.58 °C	26.34 °C
28.89 CFM	26.1 °C	25.8 °C	25.84 °C	25.58 °C
57.78 CFM	25.8 °C	25.5 °C	25.51 °C	25.22 °C

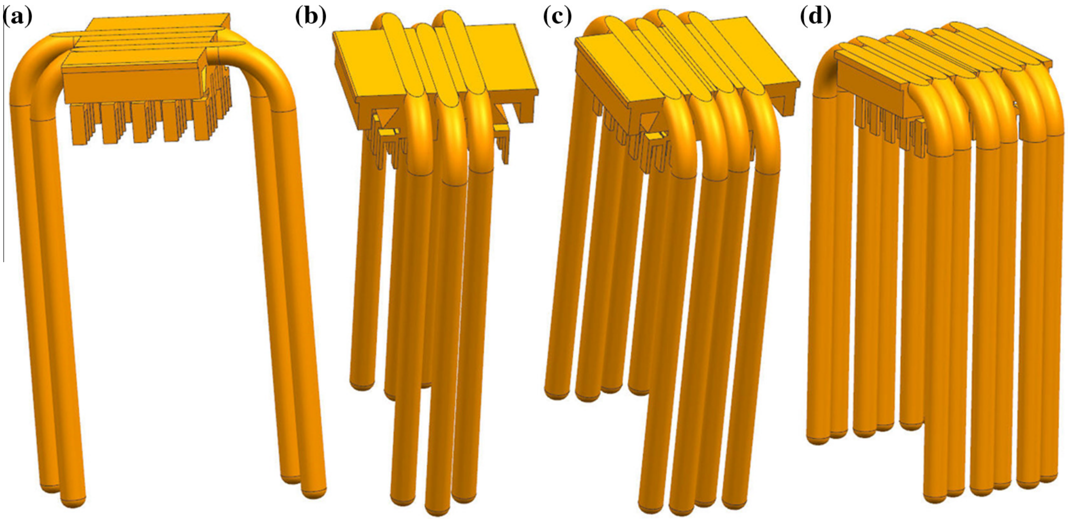

Fig. 5. Schematic of cooling system assembled with different number of heat pipes:(a) is 2 heat pipes, (b) is 3 heat pipes, (c) is 4 heat pipes, and (d) is 6 heat pipes.

bility study conditions for program verification and cooling performance examination in this work.

Condition 1: Detection for thermocouple temperature acquisition and display function.
Condition 2: Testing for PID control and fan speed control module.
Condition 3: Evaluation for reliability experiment and thermal performance.
Condition 4: Inspection for protection and alarm function.

Conditions 1–3 are easy to understand and implement. As for these conditions, the experiment can be taken under normal conditions, and additional job is not necessary. But the experimental condition 4 are different from the previous three conditions and much more adjustable. Otherwise, the alert and protection will not be triggered due to the excellent thermal performance of the cooling system. To inspect the protection and alarm function, the

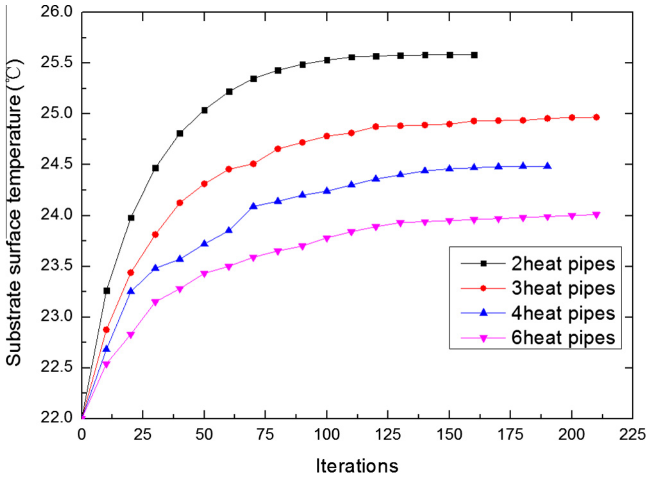

Fig. 6. Thermal performance analysis with different number of heat pipes.

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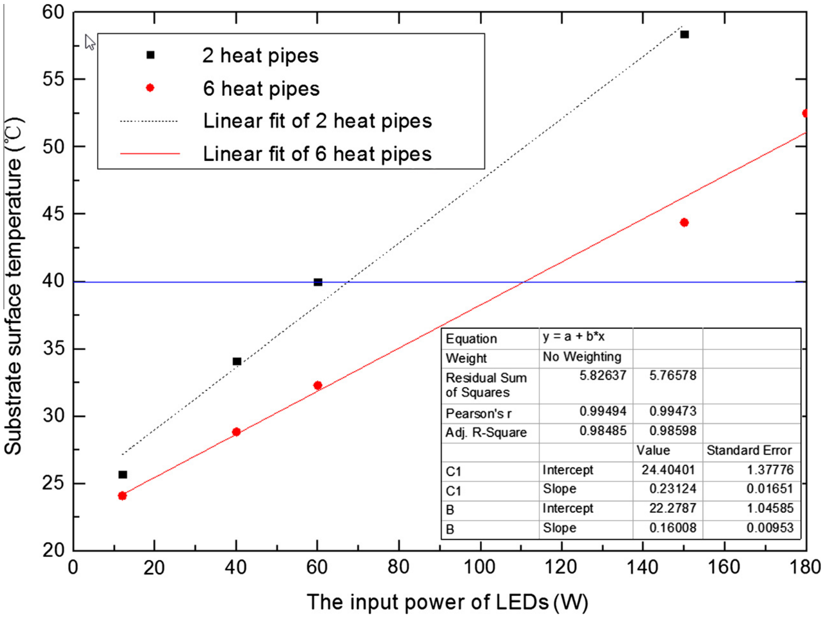

Fig. 7. Comparison of the cooling capacity with different number of heat pipes.

critical value of LED substrate temperature is altered temporarily in this section. Furthermore, malfunctions such as fan failure, can be presumed to verify the automatic protection capability of cooling system.

3. Results and discussion

High junction temperature affects performance and lifetime. Therefore, the heat dissipation performance of system can be estimated according to the level of the junction temperature. It is not convenient to measure the internal junction temperature of an operating high power LED. The temperature on substrate surface of high power LED is mainly affected by the junction temperature, and is considered and measured by using thermocouples in this study. The junction temperature can be obtained by the following equation [35]:

$$T_j = T_s + PR_{js} \tag{2}$$

where T_j is the junction temperature of LED (°C); T_s is the substrate temperature (°C); P is power dissipation of LED (W); R_{js} is the thermal resistance between the LED chip and substrate (W/K). Therefore, the substrate temperature can be used as a parameter for estimating the heat dissipation performance of cooling device.

3.1. Cooling results of automatic system

In order to evaluate the performance of the automatic cooling system, the real-time temperature of substrate of LEDs was read and displayed on the screen of 1602 LCD under different conditions. Firstly, WPM fan of cooling system was cut off. Simultaneously, the substrate temperature was displayed and recorded at the interval of 30 s, as shown in Fig. 3. The result shows that the substrate temperature reaches up to 45.2 °C when the ambient temperature is 22.4 °C.

Secondly, the control signal comes from the temperature difference between thermocouple and ambient temperature. The heat pipe automatic cooling system works properly and the variations of substrate temperature with time are shown in Fig. 3. It can be

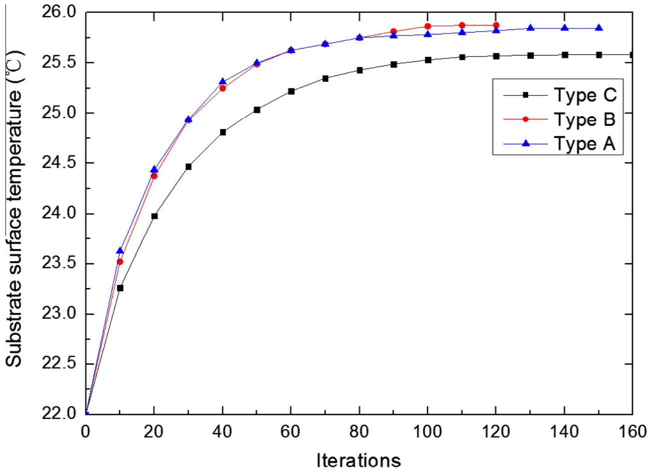

Fig. 9. Thermal performance analysis with different types of heat sink.

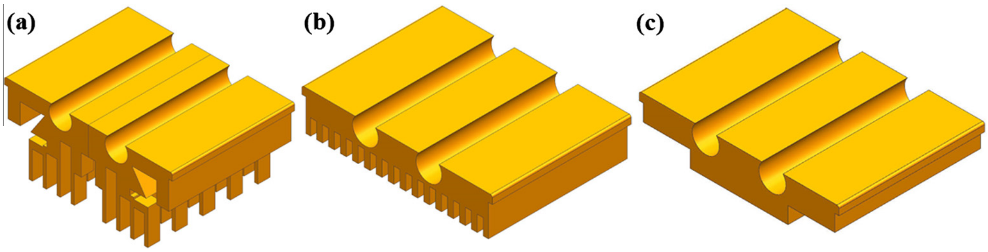

Fig. 8. 3D models of three different heat sinks: (a) is Type-A, (b) is Type-B, and (c) is Type-C.

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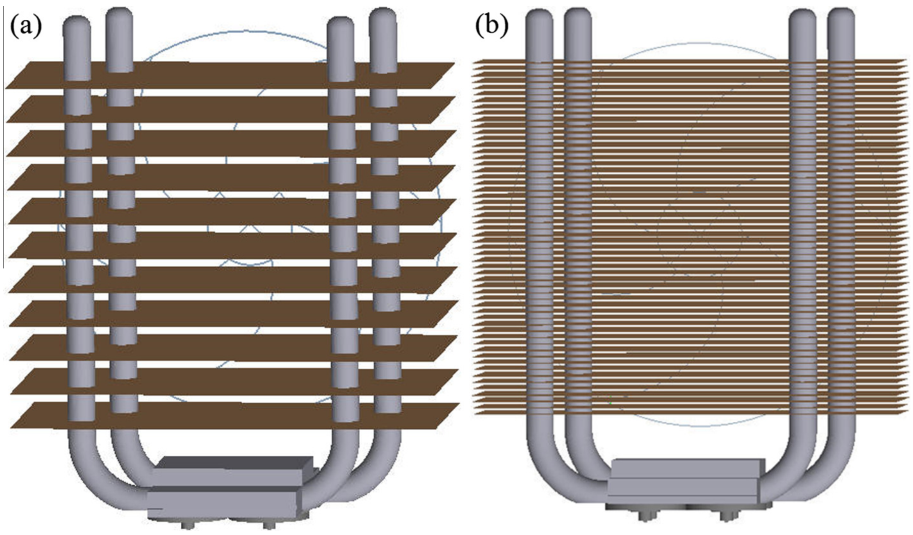

Fig. 10. Different cooling fins designs on the condenser sections of heat pipes: (a) is larger fin-pitch (8 mm); (b) is smaller fin-pitch (8 mm).

seen that the substrate temperature curve is wavy near 26.9 °C due to the cooling process driven by the microcontroller. The result indicates that the substrate temperature can be controlled effectively.

In order to further validate the cooling performance, the target (set temperature 30 °C) was treated as a controllable input signal. The substrate temperature was plotted, as shown in Fig. 3. The result exhibits that the substrate temperature is choppy in the vicinity of the target value. The other target temperature was also tested for comparison and the result is shown in Fig. 3. It demonstrates that the cooling system can automatically control the operation temperature of the high power LED.

In addition, it is found that the junction temperature of the LEDs chip was 91.5 °C when the substrate temperature was controlled at 40 °C in our previous research [33]. In other words, if the substrate temperature is less than 40 °C, the high power LEDs can work safely and reliably. Therefore, it can be considered that the substrate temperature of high-power LEDs is kept in a relative low range to protect the LEDs, which contributes a better performance and longer lifetime. And the junction temperature of LEDs can also be effectively controlled by the cooling system.

3.2. Finite-element-analysis model and validation

The experimental platform as shown in Fig. 1 was converted to characterize the thermal performance of the cooling device with heat pipes. Two thermocouples were used to monitor the temperature at evaporator of the heat pipe (point one is located at the center of the lower surface of substrate; the other point is located at the lower surface of another LED module substrate, slightly off center). The corresponding calculation domains and finite element mesh in the modeling were shown in Fig. 4 [33]. Experiments were conducted to test control module. The performance of the cooling device with heat pipes was evaluated according to the experiments. The cooling device consists of 2 pieces of heat pipes with 56 fins at the condenser sections and the PWM fan heated up by four LED modules with a heat source of 9.6 W(4 × 3 W × 80%). This test case was done for the validation of the simulation model.

The experimental results indicate that the eight function programs of the control system are a valid managed module. In addition, the heat dissipation performance of the cooling device is investigated at different fan speeds (volume flow rate varying from 7.6CFM to 57.78CFM), and the corresponding substrate temperature is recorded, as shown in Table 2. The comparison between the simulation and experimental data demonstrates that the temperature difference between the numerical and the experimental results is less than 3%, which indicates that the model is consid-

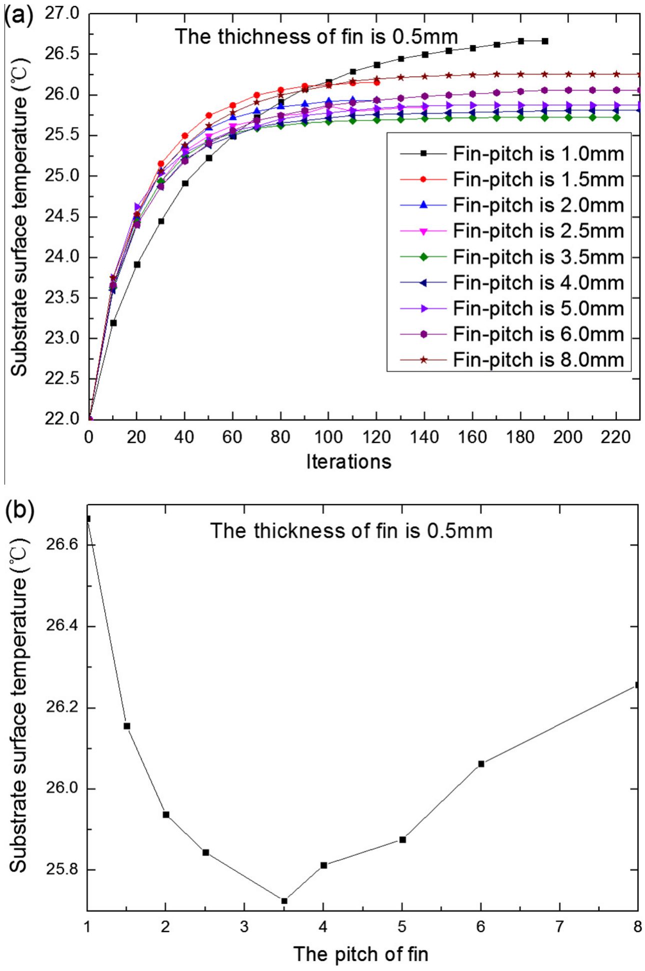

Fig. 11. Comparison of heat dissipation performance with different fin pitches: (a) is the temperature curves with different fin pitches, and (b) is steady-state temperature with different fin pitches.

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erably accurate. The maximum temperature on the substrate surface is predicted as 28.03 °C, which is 0.57 °C lower than the experimental measurement. The minimum temperature is predicted (25.22 °C) as 0.28 °C which is also lower than the experimental measurement (25.5 °C). The temperature maximum difference between monitor points of simulation is 0.29 °C, which is slightly lower than the experimental measurement (0.4 °C). The results also verify the effectiveness and feasibility of the control system in another perspective.

3.3. Improving thermal performance by heat pipe variation

Considering that adding heat pipes is one of the most effective methods for heat transfer performance enhancement in the industry and research, this kind of approach was also investigated in this study concerning the cooling performance on high power LEDs application. The cooling device with different number of heat pipes are shown in Fig. 5, namely 2 heat pipes (Fig. 5(a)), 3 heat pipes (Fig. 5(b)), 4 heat pipes (Fig. 5(c)), and 6 heat pipes (Fig. 5(d)). A comparison of the change in temperature among four conditions with fixed volume flow rate was made to highlight the effectiveness of the heat pipe. As seen from the curves in Fig. 6, the LED substrate surface temperature at steady-state is greatly reduced from 25.58 °C to 24.01 °C when the number of heat pipes increases from 2 to 6, which suggests that adding heat pipes is an effective method for heat transfer improvement of the cooling device. The parametric analysis results presented in Fig. 7 show that the cooling capacity of the system could be considerably increased from 67 W to 110 W, fulfilling the design requirement (the maximum substrate temperature below 40 °C). Obviously, the cost increases with the amount of heat pipes and the appropriate number of heat pipes can be determined according to the heat power.

3.4. Evaluation of thermal performance with different shapes of heat sink

The high power LEDs are directly attached to the evaporators of heat pipes using the heat sink Therefore, the effective heat transfer

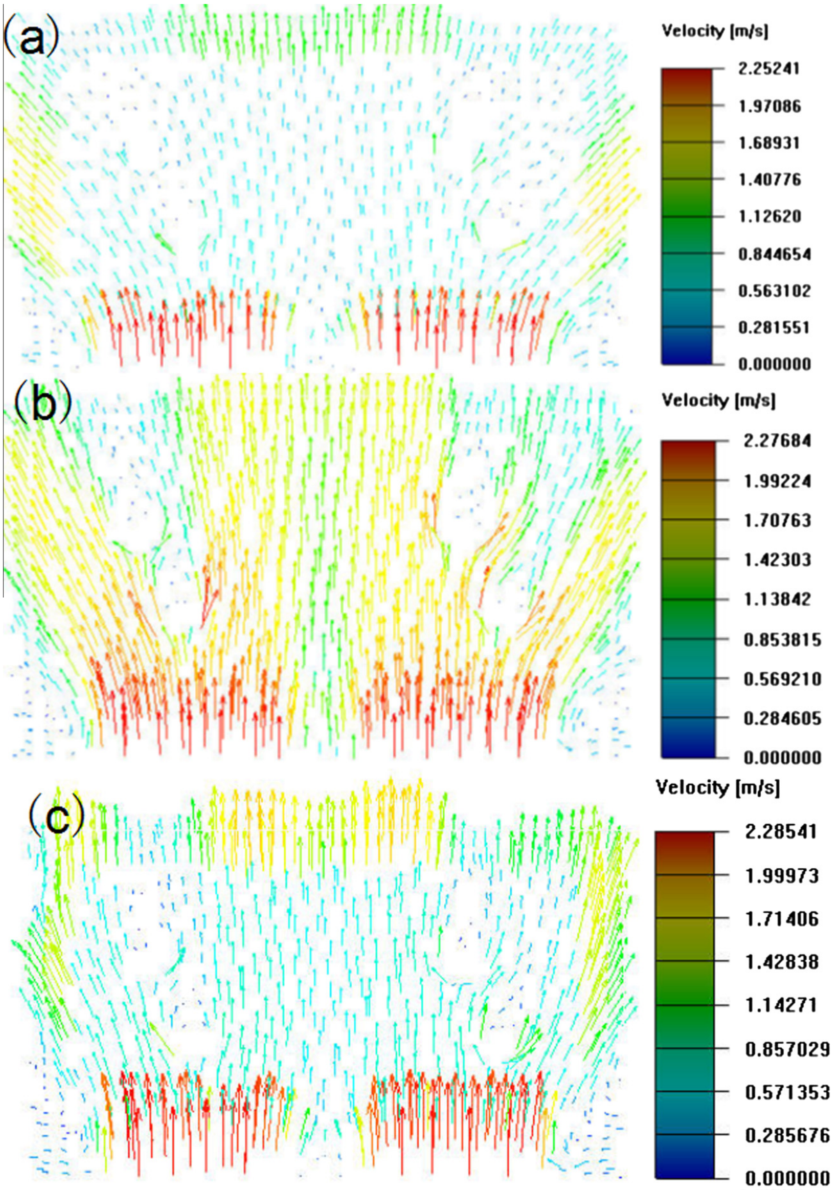

Fig. 12. Comparison of velocity profile between fins with different fin-pitches (d_{pitch}), 2 heat pipes. (a) is d_{pitch} = 1.5 mm, (b) is d_{pitch} = 3.5 mm, (c) is d_{pitch} = 5 mm.

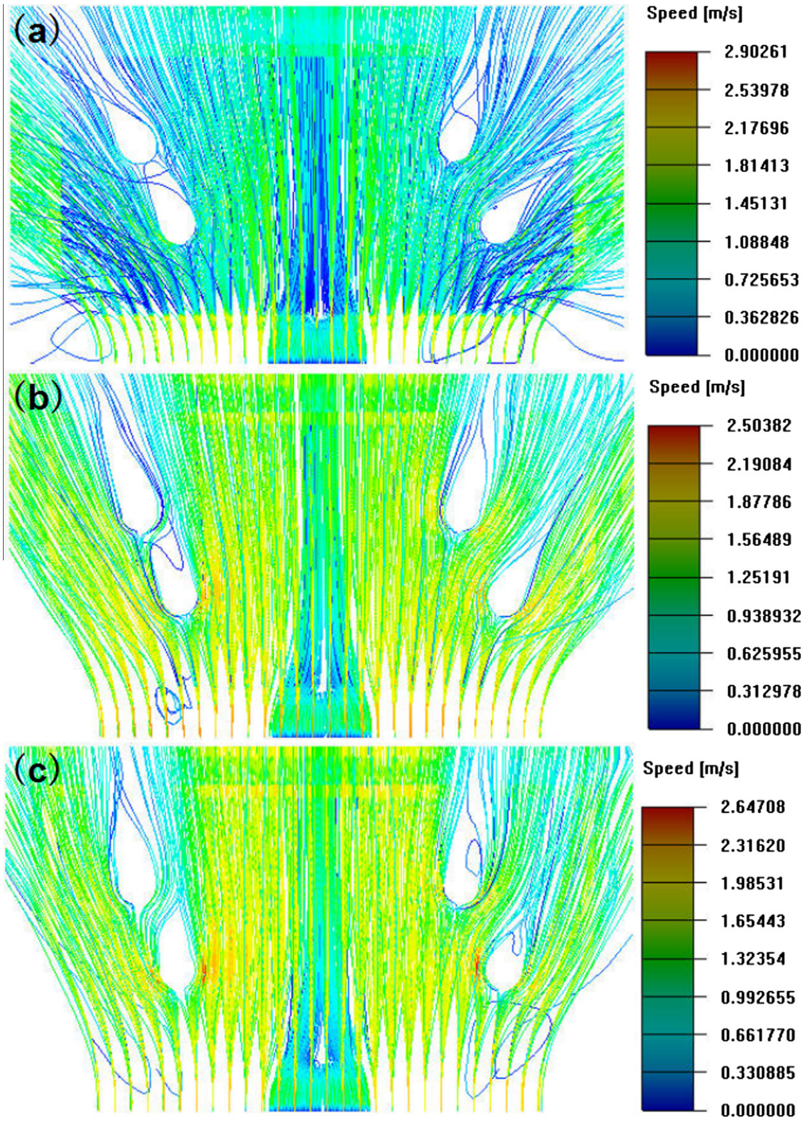

Fig. 13. Comparison of particle traces of fan with different fin-pitches (d_{pitch}), 2 heat pipes: (a) is d_{pitch} = 1.5 mm, (b) is d_{pitch} = 3.5 mm, and (c) is d_{pitch} = 5 mm.

areas are the 4 strips of contact areas filled by thermal paste of the heat sink, which is beneficial to improve the uniformity of evaporator sections temperature. Thermal grease was used to minimize the thermal contact resistance between the heat sink and the LED heat source. Furthermore, the heat sink also contributes to heat dissipation. The effects of heat sink with three different shapes, as shown in Fig. 8, were studied in this paper. As seen from the surface temperature of LED substrate in Fig. 9, the marginal effect of changing the type of heat sink on the thermal performance of the cooling device among Type-A, Type-B and Type-C becames negligible, so the simple Type-C is a more cost-effective heat sink for the heat pipe radiator design. This kind of shape would be adopted in the following studies.

3.5. Effects of the fins on heat dissipation performance

Cooling fins at the condenser sections are highly preferred by designers and manufacturers for thermal management of the heat pipe radiator. To evaluate the effectiveness of the cooling fins, numerical simulations using the present model were undertaken. Comparisons of heat dispersion were made among cooling devices with different fin pitches. As shown in Fig. 10, the design (a) is a cooling system with a large fin-pitch (8 mm) at the condenser sections, and the design (b) is a cooling system with a smaller fin-pitch (1.5 mm). In practice, eight different fin-pitches (from 8 mm to 1.5 mm) have been simulated, and the corresponding number of aluminum fins was increased from 11 to 82. The dimension of the fin is 100 mm × 50 mm × 0.5 mm. The simulation results of the surface temperature of the LED substrate equipped with different fin-pitches were plotted in Fig. 11. As shown in the figure, the heat dissipation efficiency of aluminum fins firstly increases and then decreases gradually with the increasing fin pitches.

In order to further understand the causes of the variation of heat dissipation performance, the velocity profile between fins and particle traces of fan with different fin-pitches (1.5 mm, 3.5 mm and 5 mm) were plotted in Figs. 12 and 13. They indicate that the fin-pitch has a significant impact to air flow between fins. Specifically, when the cooling system with smaller fin-pitch, air flow between fins appears the trend of the stalemate, which leads to the decrease of the heat transfer coefficient of local convection. Air velocity between fins increases with the increasing number of fin pitches, which enhances the heat transfer. However, the surface area in the shell side of the heat pipe and the intensity of turbulence will be substantially reduced with the further increasing number of fin pitches. Thus, the quantity of exchanged heat falls

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Table 3
Comparison of heat dissipation with different fin-thickness (d_{pitch} = 4 mm), 2 heat pipes.

Fin-thickness (mm)	0.5	1	1.5	2
Substrate temperature (°C)	25.8	26.49	26.53	27.5

Table 4
Thermal resistance of cooling system under different condition.

Q (W)	9.6	32	48
T_a (°C)	22	22	22
T_s (°C)	25.58	34.12	40.04
T_j (°C)	79.15	87.36	90.83
R_{sa} (°C/W)	0.373	0.379	0.376
R_{ja} (°C/W)	5.953	2.04	1.43

rapidly due to the increase of thermal resistance of convective heat transfer.

Moreover, the number of fin pitches decreases with the increasing thickness of fins. The heat transfer efficiency with different thickness of fins (0.5 mm, 1 mm,1.5 mm and 2 mm) under a certain fin pitch were investigated. The simulation results of fin with 0.5 mm thickness are presented in Table 3, which shows that 4 mm fin-pitch leads a lower surface temperature of LED substrate than other thickness. These results verify the above fin pitches analysis on heat dissipation performance.

3.6. Thermal resistance of cooling system

The simulation results provide temperature distribution, and the steady-state junction temperature of the LED chip calculated by numerical simulation was shown in Table 4. It can be seen that the highest one is only 97.1 °C, and it is satisfied with the requirement of the LED working temperature (under 120 °C). Thermal resistance selected as the performance index, is a significant parameter to evaluate the performance of cooling device. The lower the thermal resistance is, the better the performance of cooling device is. Thermal resistance is defined as follows [36]:

$$R_{ja} = T_j - T_a/Q \tag{3}$$

$$R_{sa} = T_s - T_a/Q \tag{4}$$

$$Q = Q_{input} - Q_{light} = 0.8Q_{input} \tag{5}$$

where T_j is the junction temperature of LED; T_a is the temperature of ambient; Q is the heat power of LEDs. Resistance value of the whole model is calculated for model in this study based on the simulation results. Thermal resistances R_{sa} and R_{ja} of the cooling system with the installation of heat pipes and cooling fins are 0.373 °C/W, 5.953 °C/W at 12 W, 0.379 °C/W, 2.04 °C/W at 40 W and 0.376 °C/W, 1.43 °C/W at 12 W, respectively. It demonstrates that the cooling system is active in heat dissipation and changes the thermal resistance.

4. Conclusions

In summary, the high power LEDs can be cooled efficiently and run safely by using the innovative cooling system based on heat pipes, PWM fan and the automatic control. The numerical model of the cooling system was verified by the test results, and was employed to optimize the thermal performance of the automatic cooling system. Critical values including the junction temperature of LED and the surface temperature of the LED substrate were extracted from the computational results to characterize the effectiveness of the cooling device. Numerical investigations show that appropriately increasing the number of heat pipes and cooling fins at the condenser sections will improve the thermal performance of the cooling device by increasing the cooling capacity and reducing thermal resistance of convective heat transfer. In addition, the marginal effect of changing the heat sink type is negligible on the thermal performance. The automatic cooling system has high reliability, low energy consumption and excellent cooling efficiency.

Acknowledgement

This work was supported by the National Natural Science Foundation of China (No. 51275536) and the China High Technology R&D Program 973 (No. 2015CB057206).

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Please cite this article in press as: C. Xiao et al., A novel automated heat-pipe cooling device for high-power LEDs, Appl. Therm. Eng. (2016), http://dx.doi.org/10.1016/j.applthermaleng.2016.10.041

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Please cite this article in press as: C. Xiao et al., A novel automated heat-pipe cooling device for high-power LEDs, Appl. Therm. Eng. (2016), http://dx.doi.org/10.1016/j.applthermaleng.2016.10.041