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Thermal Analysis of Aluminum-Acetone Flat Plate Heat Pipe Application in Heat Dissipation of High Power LEDs

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Abstract. The energy resources of nature are limited. According to the report from the International Energy Agency (IEA), there is 19% of the energy used for illumination. It's well known that LED is an excellent choice to instead the incandescent lamp for saving energy. But the other question comes out while the high power LED is applied. There is only about 20% of the input power converts to light energy, the rest of power is convers to heat which should be carry out from the LED chips, otherwise, the high heat concentration results in a serious problem to decrease LED working. The most important issue of the LED research is to find a potential design of heat removal and solve the problem of LED over-heating. The purpose of this study is to discuss the heat removal ability of the aluminum-acetone flat plate heat pipe by applying in the high power LED array. The aluminum-acetone flat plate heat pipe is innovative proposed by our team. The high power LEDs with and without heat pipe cooling module is compared. The heat removal efficiency of the cooling module of the aluminum-acetone flat plate heat pipe reaches 92.09% and drops the junction temperature of LED about 36 ℃. The thermal resistance is discussed. The cooling module of the aluminum-acetone flat plate heat pipe has proven to be effective in solving the heat concentration problems associated with the LED chips. In short, the phase change cooling module will apply on the electronic component of high heat concentration for more effective cooling method.

Keywords: Aluminum-acetone flat plate heat pipe; high power LEDs; thermal analysis

1. Introduction

The energy resources of nature are limited. People find new kind of alternative energy and new methods to save energy. According to the report from the International Energy Agency (IEA) [1], there is 19% of the energy is used for illumination. The energy cost of illumination is a huge number. Many countries and regions promote energy conservation policy to phase out incandescent lamps. The LED is an excellent choice.

The advantages of LED are small size, long lifetime, fast response, high lighting efficiency, anti-impact and colorful. But the issue of heat dissipation of LED still exists seriously. In addition, the tendency of small size results in the huge heat concentration, it makes the heat of high-power LED dissipates more difficult.

A lot of studies about heat dissipation of LED have been investigated by previous researches. The traditional method for heat removing is to use the huge heat sink or cooling fan. Wang [2] uses heat sink to cool down the high power LEDs and analyzes the results of different fins setting. Costa et al. [3] propose a numerical study of cylindrical heat sink above on the LED lamp heat sources by simulation of ANSYS. Sufian et al. [4] use piezoelectric fans for dissipation of high power LED array. The optimization of LED package is done by our team [5] for the optimal heat removal of LED chip. In 2011, the optimal arrangement of LED array is proposed for avoiding the high concentration of the power density [6]. Bladimir et al. [7] propose a cooling device of micro jet channel to cool the high-power LED array. Hsieh et al. [8] propose a micro spray based cooling system to cool down the temperature of high-power LED. Li et al. [9] propose the loop-heat-pipe heat sink for cooling the LEDs. As the application of heat pipes becomes more wildly, more attention on the operation of heat pipes has appeared plentiful recently. Lips and Lefèvre [10] develop a general model for conventional heat pipe to analyze flat plate heat pipes and cylindrical heat pipes. Comparing with traditional heat pipe and flat plate heat pipe, the plate heat pipe has the larger area to dissipate heat, which can reduce spreading thermal resistance and increase heat transfer efficiency. The innovative aluminum-acetone flat plate heat pipe is proposed and fabricated by our team [11]. This paper designs and manufactures the aluminum-acetone flat plate heat pipe module for passive-cooling high power LEDs, which results in the excellent potential of heat removal. In addition, it builds a numerical model to simulate the experiment for the optimization. It is not only applying on the high power LEDs but also medium-temperature cooling applications of electronic component.

2. Theoretical Background

Thermal resistance of a single apparatus is defined as:

$$R_{th} = \frac{T_J - T_X}{Q} \tag{1}$$

The efficiency of heat removal can be calculated by the following equations:

$$\eta = \frac{Q_{heatpipe}}{Q_{total}} \tag{2}$$

$$Q_{total} = Q_{heatpipe} + Q_{convection} + Q_{luminous} \tag{3}$$

η : Efficiency of heat removal
Q_{heatpipe}: the heat moved by heat pipe
Q_{total}: the total power of LEDs
$Q_{\text{convection}}$: heat moved by convection
Q_{luminous} : luminous power

The total power of LEDs is calculated by the input voltage and current. The heat moved by convection can be calculated by the Newton's law of cooling. The heat convection coefficient on the surface boundary condition should be assumed as the nature convection. The efficiency of luminous is came from manufacturer information.

3. Experiment Apparatus and Procedure

We mounted 21 High power LEDs on the copper substrate and measured the characteristic temperatures by thermocouples. After that, set 2 cases to measure the experiment data. One is the high power LEDs array working without heat pipe cooling module, the other is working with it.

Fig. 1. The high power LEDs array without cooling module.

As shown in the Fig. 1, the test part of the substrate is made of copper; and the length, height is 85 mm, 37 mm, 2 mm. 21 LEDs arranged as a 3*7 array. In addition, the diameter of LED is 9mm. The LEDs and T-type thermocouples are mounted on the substrate by OMEGA 600. The position where the thermocouple measured is the junction of LED and substrate. For the purpose of heat removal, the space below the copper substrate is kept the suitable space for the natural convection. The LEDs array and heat pipe cooling module is shown in the Fig. 2.

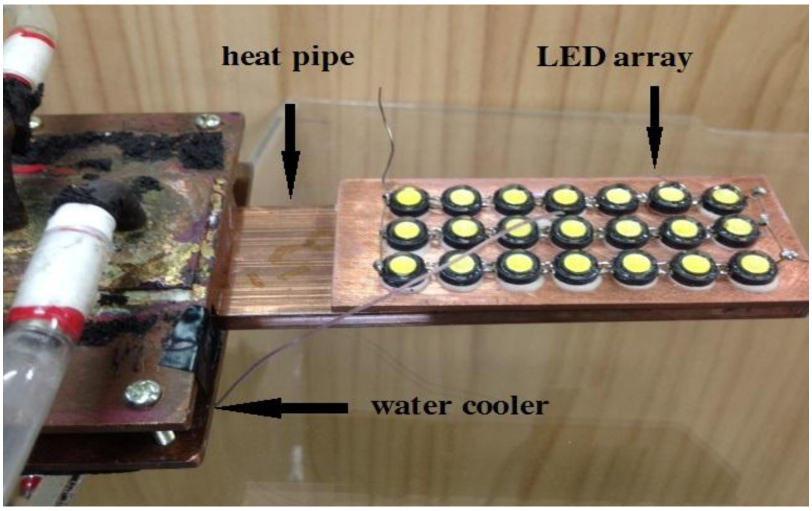

Fig. 2. The LEDs array and heat pipe cooling module.

The cooling module is an aluminum-acetone flat plate heat pipe combined with a water cooler. The water is circulating fluidized by a thermostatic water bath. It keeps the temperature of water stable at 25 ℃.

In this study, the maximum power of LEDs array is 20.61W as the current is 0.9A.

The experimental schematic diagram is shown in Fig. 3.

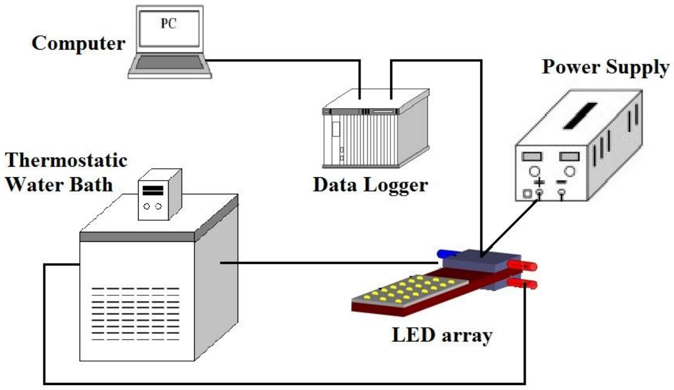

Fig. 3. Experimental schematic diagram.

As it is shown in Table 1, there are 3 different power will be test in this system, as the current are 0.3A, 0.6A, 0.9A.

Table 1. Experimental input power (Total Power)

Current	Voltage	Total Power	Time
A	V	W	H
0.30	20.9	6.27	1
0.60	22.2	13.32	1
0.90	22.9	20.61	1

4. Results and Discussions

Fig. 4 shows the temperature profiles of LED array without/with cooling module under the different input power .The input power is 6.27W, 13.32W, and 20.61W, respectively. Throughout Fig. 3, the temperature increases as the input power increases. The maximum temperature is 161 ℃ as the input power is 20.61W. It is over-heating for a working LED. Obviously, high power LED array cannot work in a long time under this temperature. Then, the cooling module of heat pipe is added on this LED array. The temperature decreases obviously as the cooling module is added. The maximum temperature with cooling module is 36 ℃ as the input power is 20.61W.

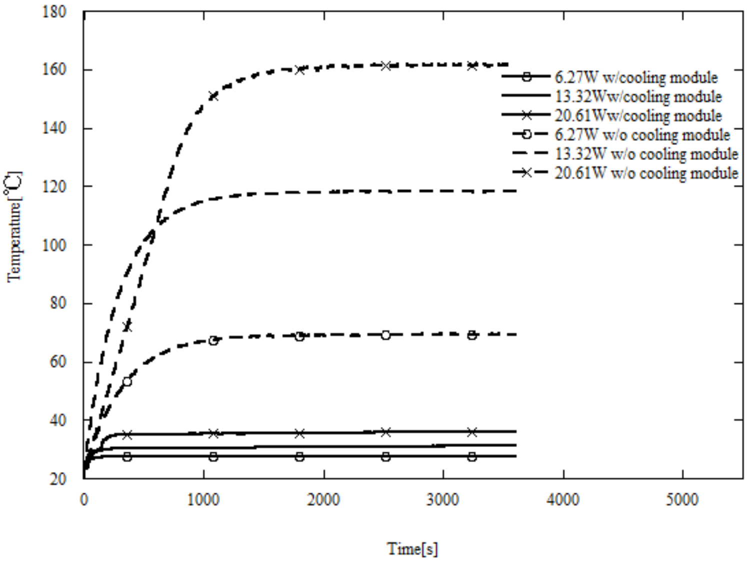

Fig. 4. The temperature profiles of LED array working with/without cooling module under different power.

The thermal resistance network of LED array working without heat pipe cooling module can be described as Fig. 5. The other case is shown in Fig. 6.

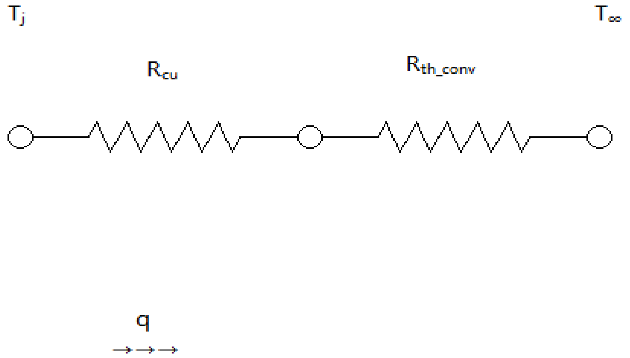

Fig. 5. The thermal resistance network of LED array w/o heat pipe cooling module.

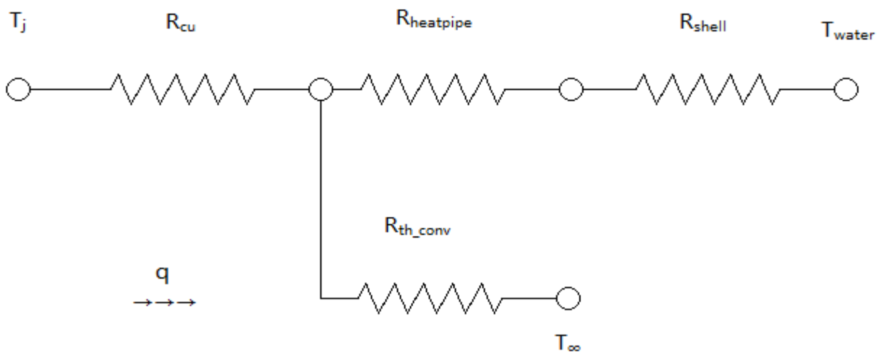

Fig. 6. The thermal resistance network of LED array w/ heat pipe cooling module.

In this study, the junction temperature is almost the same as the next side of the copper substrate. The resistance of heat convection is calculated by formula 1 as the result is 8.5 K/W. The heat pipe cooling module is in parallel with nature convection, it can be calculated by this equation:

$$R_{heatpipe} = \frac{R_{con} \cdot R_{th}}{R_{con} - R_{th}} \tag{4}$$

The thermal resistance of the heat pipe cooling module is 0.57K/W.

In this study, the temperature with cooling module is compare with the one without cooling module. We find that the heat removal efficiency of the heat pipe cooling module reaches to 92.09% as the input power is 20.61W. The detailed efficiency with various input power is listed in the table 2. In this study, we prove that the excellent capability of the heat pipe cooing module. It will enhance the heat removal of LED array effectively.

Table 2. Experimental Parameters

Power	Without heat pipe	With heat pipe	Efficiency of heat dissipation
W	℃	℃	%
6.27	61	27	95.28
13.32	118	31	93.33
20.61	161	36	92.09

5. Conclusions

The purpose of this study is to discuss the heat removal ability of the aluminum-acetone flat plate heat pipe by applying in the high power LED array. The high power LEDs with and without heat pipe cooling module is compared in this study. The heat removal efficiency of the cooling module of the aluminum-acetone flat plate heat pipe reaches 92.09% and drops the junction temperature of LED about 36 ℃. The thermal resistance of aluminum-acetone flat plate heat pipe cooling module is 0.57K/W. The cooling module of the aluminum-acetone flat plate heat pipe has proven to be effective in solving the heat concentration problems associated with the LED chips. In future, the optimization will be processed for optimizing the design of the heat pipe cooling module with the data from this experiment. We expect that this innovative aluminum-acetone flat plate heat pipe cooling module can be applied on the electronic cooling field successfully.

6. Acknowledgements

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7. References

[1] International Energy Agency, Light's Labour's Lost-Policies for Energy-efficient Lighting, 2006

[2] Wang, J.C., "Thermal module design and analysis of a 230 W LED illumination lamp under three incline angles," Microelectronics Journal 45: 416-423, 2014.

[3] Costa, V.A.F. and Lopes, A.M.G., "Improved radial heat sink for led lamp cooling," Applied Thermal Engineering 70: 131-138, 2014.

[4] Sufian, S.F., Fairuz, Z.M., Zubair, M., Abdullah, M.Z. and Mohamed, J.J., "Thermal analysis of dual piezoelectric fans for cooling multi-LED packages," Microelectronics Reliability 54: 1534–1543, 2014.

[5] Lin, D. T. W., Huang, C. N. & Chang, C. C., "The optimization of the heat removal on the LED package," Advanced Science Letters 4: 2301-2305, 2011.

[6] Hsieh, J. C., Lin, D. T. W. &Cheng, C. H., "Optimization of thermal management by the integration of SCGM, finite element method and experiment on the high power LED array," IEEE Transaction on Electron Devices 58: 1141-1148, 2011.

[7] Bladimir, R. A., Feng, B. & Peterson, G. P. "Comparison and optimization of single-phase liquid cooling devices for the heat dissipation of high-power LED arrays," Applied Thermal Engineering 59(1–2): 648-659, 2013.

[8] Hsieh, S.S., Hsu, Y.F. &Wang, M.L., "A microspray-based cooling system for figh powered LEDs," Energy Conversion and Management 78: 338-346, 2014.

[9] Li, J., Lin, F., Wang, D. & Tian, W., "A loop-heat-pipe heat sink with parallel condensers for high-power integrated LED chips," Applied Thermal Engineering 56(1–2): 18-26, 2013.

[10] Lips, S. & Lefèvre, F., "A general analytical model for the design of conventional heat pipes," International Journal of Heat and Mass Transfer 72: 288–298, 2014.

[11] Yang, Z. W., Hsieh, J. C., &Lin, D. T. W., "An experimental study for compatibility of the aluminum-acetone flat plate heat pipe," The 1st International Conference of Multi Disciplines of Engineering on Advanced Technology and Environmentalism Design, Pattaya, Thailand, 6-8 Mar, 2012.