Applied Thermal Engineering 123 (2017) 19–28

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Heat dissipation of high-power light emitting diode chip on board by a novel flat plate heat pipe

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HIGHLIGHTS

- A new flat plate heat pipe is designed and fabricated.
- This new heat pipe is used for heat dissipation of high power LED COBs.
- An experimental system is set up and an ICEPAK model is established.
- Numerical simulation results accord well with experimental data.
- The system based on the new heat pipe lowers the thermal resistance by 10–15%.

ARTICLE INFO

Article history:
Received 28 December 2016
Revised 28 April 2017
Accepted 9 May 2017
Available online 17 May 2017

Keywords:
Flat plate heat pipe
Light emitting diode
Electronics cooling
Heat dissipation
Chip on board

ABSTRACT

A new flat plate heat pipe (FPHP) which has many parallel-arranged micro-fins casted on the condensation surface was designed and fabricated. An experimental system for studying the thermal performance of this FPHP when applied for cooling high-power LED (light emitting diode) COBs (chip on board) was also set up. From experiments, the new FPHP is found to be more effective for heat dissipation of high-power LED COBs than the traditional FPHP. The thermal resistance of the new FPHP is 10–15% lowered and the temperature uniformity at the condensation surface of FPHP is approximately at the same level in comparison with the traditional FPHP. Numerical simulation with respect to LED COB cooling by the new FPHP was performed additionally. The obtained simulation results accord well with the experimental results, inter-proving the reliability of the obtained results and further corroborating the effectiveness of the new FPHP as applied for heat dissipation of high-power LED COBs.

1. Introduction

The light emitting diode (LED) is becoming an ideal residential and outdoor light source. In conventional applications, LED packages were mostly in a single-chip form with a small fluorescent area, which leads to heat concentration. The manufacturing process of a single-chip LED is generally complicated and costly. These make the single-chip LED packages unable to meet the requirements of modern lighting [1–3]. Moreover, to enhance the brightness of LED lamp, it commonly consists of a combination of multiple LED chips, which further increases the cost and generates more waste heat. An LED packaging structure, chip on board (COB) [4,5], thus came into public view. The COB package directly mounts multiple naked LED chips on a printed circuit board (PCB), and then performs the wire bonding, puts the packaging materials on the chip, and last distributes wires for package protection [6]. Due to the unique way of packaging and heat dissipation structure, the COB is adopted in manufacturing miscellaneous LED lamps, such as LED bulb lamp (for residential use) and LED street lamp, LED wash wall lamp (for outdoor use).

The COB has multi-chips placed on a metal plate, enhancing the luminous flux, the power of overall light source and the luminous efficiency, at the same time, effectively avoiding dazzle [7,8]. The single-chip LED light needs reflow soldering, during which the high soldering temperature may cause great damage to the LED chip. The COB does not need reflow soldering; this not only reduces the investment of equipment and the manufacturing cost of LED lamps, but also improves the reliability of LED products [9]. In addition, the COB can save some materials like lead frame, pin, and solder, simplifying the secondary optical design and saving the assembly cost. For high-power COB LEDs, hotspots due to waste heat cause high temperatures at junctions, that is to say,

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http://dx.doi.org/10.1016/j.applthermaleng.2017.05.039
1359-4311/

Nomenclature

A or A'	area, m^2
H	height, m
L	length, m
l	thickness, m
Q	heat power, W
R	thermal resistance, °C/W
S	heat flux, W/m^2
T	temperature, °C
W	width, m

Greek symbols

λ	thermal conductivity, W/m·°C
δ	distance, m

Subscripts

h	heat
x, y, z	Cartesian coordinates

Abbreviations

ANSI	American national standards institute
ASME	American society of mechanical engineers
CAE	computer-aided engineering
COB	chip on board
DC	direct current
FPHP	flat plate heat pipe
LED	light emitting diode
PC	personal computer
PCB	printed circuit board
PPI	pores per inch

the heat dissipation remains to be still a severe issue. To keep the LED chip working below 110 °C for longer lifetime and higher luminous efficiency [10–13], resolving the heat dissipation issue of COB LEDs is of considerable significance.

Currently, the strategies for heat dissipation of high-power LEDs are mainly classified as: heat sink, forced convection, and heat pipe. The heat sink can improve the cooling capacity by increasing the surface area of the heat dissipation fins, but it is constrained by the space for installation [14–17]. The forced convection has excellent cooling effects; however, it needs to consume external pump work, generates noise and may lower the reliability of system [18,19]. The heat pipe has been applied to the heat dissipation of LEDs, but there is still plenty of room for performance improvements and conceptual innovations [20,21].

The flat plate heat pipe (FPHP) is a relatively new type of heat pipe. Like the conventional heat pipe, the FPHP relies also on the evaporation and condensation of a working fluid to achieve efficient heat transport. The FPHP is of more simple structure than and has some additional advantages over the conventional heat pipe. For instance, the FPHP may be more light-weighted [22]. The FPHP has the potential to be widely used for the cooling of LED lamps. Hsieh et al. [23] reported a work using a hybrid FPHP structure composed of grooves, mesh screens, and a coronary-stent-like supportive structure to cool a high-power LED module. The experimental result showed that the hybrid FPHP enhanced fluid capillary flow and thus lowered thermal resistance of LED heat dissipation. Wang et al. [24] proposed a FPHP-based cooling plate for a 30 W LED lamp. The FPHP cooling plate additionally reduced the LED junction temperature by >10 °C, compared with an aluminum-based heat sink.

Numerous studies were conducted to relate the FPHP performance with its inner structure. Wong et al. [25] analyzed the performance of a FPHP with a novel vapor chamber with parallel grooves corrugated on its top plate. This specially structured vapor chamber facilitated the liquid-flow and improved its anti-dryout property. Lefèvre et al. [26] presented two FPHPs with different capillary structures. One had a capillary structure consisting of one or two screen mesh layers, while the other FPHP used screen-mesh-covered grooves as its capillary structure. The FPHP with two layers of mesh did not show a larger capillary force than the FPHP with one layer mesh. The thermal performance of the FPHP with mesh-covered grooves was not good as expected due mainly to the limited nucleation boiling. Zhang et al. [27] put forward a FPHP of a special vapor chamber, in which a boiling pool is in the middle, and a circular groove at the edge acting as the liquid storage channel. The FPHP was found to have good heat transfer performance in the axial and radial direction, probably better than that of solid copper plate when the thickness of vapor chamber plate was small. Peng et al. [28] investigated the heat transfer performance of a novel FPHP, which was installed with some perforated fins in the fluid cavity to enhance the evaporation of fluid. They found the non-condensable gas could lower the boiling point of the working fluid and the vacuum degree thus had a significant influence on the thermal performance of the FPHP. Lips et al. [29] predicted the performance of the FPHP with micro-grooves. The filling ratio and the vapor space thickness were combined to affect the liquid distribution in and the thermal performance of the FPHP.

It is speculated that using FPHP for LED heat dissipation can decline the total thermal resistance and improve the heat transfer performance. The present work reports the design and fabrication of a novel FPHP, which has many parallel-arranged micro-fins casted on the condensation surface of its vapor chamber. We set up an experimental system to study the thermal performance of this FPHP when applied for cooling high-power LED COBs. A numerical study is also performed to corroborate the effectiveness of using this FPHP for cooling of high-power LED COBs. Hence, the paper consists of two parts. The first part reports the design and fabrication of the novel FPHP and the experimental study on the thermal performance of this FPHP used for cooling high-power LED COBs. Thermal performance of a conventional FPHP is also tested for comparison. The second part deals with an ICEPAK® numerical simulation to attain the temperature distribution of LED COBs cooled by the FPHP. The present work is expected to provide a theoretical basis and some technological instructions in what concerns applying the FPHP for LED COB cooling.

2. Experimental

2.1. The multi-chip LED COB

The multi-chip LED COB is shown in Fig. 1. The COB is an integrated package consisting of multiple LED chips, a copper base plate, fluorescent gel and two pins, as shown in Fig. 1(a). The power of the LED COB is 20 W, 30 W or 50 W depending on the chips integrated. The power of each single chip is 1 W. The chips are arranged and fabricated in the way of 10 in serial and n ($n = 2$, 3 and 5 for the 20 W, 30 W, and 50 W COB, respectively) serials in