Applied Thermal Engineering 66 (2014) 632–639

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

A high power LED device with chips directly mounted on heat pipes

Yong Tang, Xinrui Ding*, Binhai Yu, Zongtao Li, Bin Liu

Key Laboratory of Surface Functional Structure Manufacturing of Guangdong High Education Institutes, School of Mechanical and Automotive Engineering, South China University of Technology, Guangdong, PR China

HIGHLIGHTS

- A novel columnar heat pipe (CHP) leadframe for LED package was developed and tested.
- 42 high power LED chips were directly mounted on the surface of the CHP leadframe.
- The leadframe can reduce the thermal resistance efficiently.
- The CHP leadframe has high luminous efficacy and low chromaticity shift.

ARTICLE INFO

Article history:
Received 11 September 2013
Accepted 23 February 2014
Available online 12 March 2014

Keywords:
Heat pipe
LED arrays
Thermal resistance
Chromaticity shift

ABSTRACT

A novel columnar heat pipe (CHP) leadframe for high power LED device was developed. 42 high power LED chips were mounted on its surface directly. The thermal performance, luminous and chromaticity of the CHP leadframe base LED device are tested and discussed experimentally. The obtained results show that the thermal resistances $R_{\text{l-s}}$ (from the leadframe to the heat sink) and $R_{\text{j-a}}$ (from the LED chip to the ambient) of the CHP leadframe are 0.23 °C/W and 1.65 °C/W at 2800 mA, respectively. The luminous efficacy of the CHP leadframe LED device is 66.23 lm/W at 2800 mA. It is 19.2% higher than the conventional copper leadframe LED device. The correlated color temperature (CCT) shift value of the CHP leadframe is 381 K and it is lower than that of the copper leadframe by 23.5%. The discussed results show that the CHP leadframe has an outstanding performance for high power LED lighting.

1. Introduction

For the past few years, high power light emitting diodes (HP-LEDs) have greatly accelerated the process of replacing the conventional general lighting due to their energy savings, light weight, short response time and long lifetime [1–3]. Now, the highest luminous efficiency of a single chip HP-LED package has reached 276 lm/W at laboratory level [4]. But even so, it still does not fit all practical applications, such as street lamp, high bay light or automotive head light. For these cases, the illumination is needed up to 3000 lm/lamp or even more [5]. Multi-chip LED modules are excellent candidates for such applications. Under the current level of technology, 70%–85% of the input power of HP-LEDs will be consumed as heat dissipation [6]. The heat flux is usually on the magnitude of 300 W/cm^2 at the chip scale, and there will be a considerable heat accumulation in the modules at the package level. If the heat cannot be dissipated efficiently, the junction temperature (T_j) would rise up rapidly. And this will induce a series of problems [7,8].

For multi-chip LED applications, a large assembly area of device is always required to form a sufficient contact for heat dissipation. In order to reduce the heat sink dimensions, active cooling methods such as micro-jet array cooling [9–11], liquid metal cooling [12], forced convection cooling [13,14], electro-hydrodynamic approach cooling [15] were applied in system level. The disadvantages of these methods such as high cost, complex design and decreasing efficiency of the system are conspicuous and those have greatly restricted the commercial applications. Heat-pipe technology is an alternative efficient cooling method, serves the lights as an important thermal management approach. There were different types of heat pipe cooling method for HP-LEDs systems. Kim et al. found that the use of heat pipe and forced convection decreased the junction temperature of six LED packages mounted on a metal core printed circuit board to 59.7 °C at an ambient temperature of 15 °C and input power of 18.1 W [14]. Lu et al. used a flat heat pipe heat

---

* Corresponding author.
E-mail addresses: ding.xinrui@mail.scut.edu.cn, dingxinrui-1987@163.com (X. Ding).

http://dx.doi.org/10.1016/j.applthermaleng.2014.02.067
1359-4311/

Nomenclature

P_{cap}	capillary pressure [Pa]
P_v	vapor pressure [Pa]
P_l	liquid pressure [Pa]
P_g	pressure caused by gravity [Pa]
K_w	permeability of the wick [m^2]
A	surface/cross section area [m^2]
Q	heat load [W]
K	factor of relationship between temperature and voltage [V/°C]
V	voltage [V]
I	current [A]
T	temperature [°C]
R	thermal resistance [°C/W]
P	power [W]
r_e	effective Capillary radius [m]
d	diameter of power particle [m]
m	mass flow [kg]
h_{fg}	latent heat [kJ/kg]

Greek symbols

σ	surface tension [kg/s^2]
μ	dynamic viscosity [Ns/m^2]
ρ	density [kg/m^3]
ε	voidage

Subscripts

avg	average
j	junction
l	leadframe
s	heat sink
a	ambient
j-l	junction to leadframe
l-s	leadframe to heat sink
s-a	heat sink to ambient
j-a	junction to ambient
h	heat
el	electrical
opt	optical

sink for high power LED and the total thermal resistance of LED system was 8.8 K/W at 3 W [16]. Vapor chamber has a low spreading resistance which is 0.38 K/W from Wang and his co-workers' research [17]. Huang et al. applied a lamp-type vapor chamber to HP-LED systems in natural convection and showed that the spreading resistance was lower than the metal plate by 34% at 30 W [18]. Lu et al. invested the thermal performance of the loop heat pipe applied in HP-LED systems and Li et al. studied the uneven-distribution phenomenon with a dual parallel condensers loop heat pipe applied in an aluminum base LED at different input power experimentally [19,20].

Conventional heat pipes are difficult for LED packaging as their cylindrical geometry. Therefore, the evaporator side of a heat pipe is usually embedded into a metal plate which has a flat surface to assemble the LED source. In this way, some interface materials are introduced and they increased the thermal resistance of the device. As for vapor chambers or flat heat pipes, the heat is mainly dissipated in the horizontal space but limited in the vertical space because of their thin thickness. Therefore, the area of the vapor chamber has to be larger than the LED source to meet the demand of heat dissipation. Our previous report also proved that the performance of the vapor chamber under a concentrate heat source was better than under a depressed heat source [21]. Moreover, in the existing literatures and common commercial LED lamps, the LED chips are mounted on a base plate with printed circuit. Obviously, the thermal dissipation path of these applications is not optimal due to the introducing of additional thermal interfaces materials. The ultimate blueprint of heat-pipe LED systems was that chips were directly mounted to the surface of heat pipes with as less assembly area as possible. Only few of the researches concerned about such systems so far to the best knowledge of the authors.

In this paper, a novel columnar heat pipe (CHP) leadframe for cooling high power multi-chip LED device was developed. 42 high-power LED chips were mounted on its bottom surface directly. The thermal characterizations of the CHP including star-up performance and heat transfer performance with different input current were investigated experimentally. The thermal resistance network was established and an IR camera was used to show the temperature distribution of the whole LED device. The light output and chromaticity performance were also evaluated.

2. Description of the CHP leadframe

A novel columnar heat pipe (CHP) leadframe for high power LEDs package is developed and its schematic diagram is shown in Fig. 1. 42 pieces of commercial GaN-based LED chips (CHIMEI® 36 × 36 mil^2, dominant wavelength 455.0 nm–457.5 nm) were mounted on the bottom surface of the CHP leadframe directly. And the chips were connected with a 6-series and 7-parallel wire bonding connection, as shown in Fig. 1(c). OE6650 Dow Corning® silicone ($n \approx 1.54$) was used as the encapsulant material mixed with yellow phosphor (YAG).

Compared with the conventional heat pipe components, the CHP leadframe has two significant characteristics. (1) It has a polished platform at the center of the evaporator and an annular PCB for electrical connection, so the LED chips can be directly mounted on it. (2)It can spread the heat along the vertical direction, thus reducing the horizontal dimensions of the heat sink. The significant parameters of the CHP are listed in Table 1.

The fabrication steps of the CHP are as follows. (1) The spherical copper powders are filled in the copper tube with a graphite core rod, and then sintered at 900–950 °C for 60 min under hydrogen reducing atmosphere to form the wick. (2) An upper cover is assembled into the top of the tube and a vacuum pumping is used to vacuumize the inner chamber of the CHP. (3) The working fluid is filled into the CHP, and then it is sealed. The charging amount of the working fluid is based on the total volume of the porosity of the wick. Under steady state condition, the working fluid is circulated by the heat load supplied to the evaporator and the capillary forces originated from the porous wick structure and the gravity. The surface of the platform at the center of the evaporator is polished, and all the surfaces of the CHP are electroplated with silver finally.

Sintered powders are very common materials used as the wick of heat pipes [22]. In order to keep the working fluid circulation, the maximum capillary pressure generated by the wick must be greater than the total pressure drop. It can be represented by the following relation:

$$\Delta P_{cap,max} \geq \Delta P_v + \Delta P_l + \Delta P_g \tag{1}$$