Applied Energy 223 (2018) 383–400

Contents lists available at ScienceDirect

Applied Energy

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

Review of applications and developments of ultra-thin micro heat pipes for electronic cooling

Heng Tang[a], Yong Tang[a,*], Zhenping Wan[a], Jie Li[a], Wei Yuan[a], Longsheng Lu[a], Yong Li[a], Kairui Tang[b]

[a] *Intelligent Manufacturing Engineering Laboratory of Functional Structure and Device in Guangdong, School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou 510640, PR China*

[b] *Mechanical Engineering, Pennsylvania State University, Harrisburg, PA 17057, United States*

HIGHLIGHTS

- A review of the applications and developments of UTHPs for electronic cooling is reported.
- The UTHPs are particularly suitable for the heat dissipation of ultra-slim portable electronic devices.
- The sintered mesh/fibres are the most commonly used wick structures for UTHPs in actual production.
- The flattened thickness exerts significant influence on the thermal performance of UTHPs.

ARTICLE INFO

Keywords:
Ultra-thin micro heat pipes
Wick structures
Thermal management
Electronic cooling

ABSTRACT

The development of miniaturization and high-density packaging of electronic components demands heat dissipation components that are compact and exhibit high performance. An ultra-thin micro heat pipe (UTHP), as a novel heat pipe with a flat shape that is highly suitable for application with high power and limited heat dissipation space, has been extensively investigated and widely used in mobile electronics. Understanding the influence of the manufacturing processes, capillary wick structures and flattened thickness on the thermal performance of UTHPs has been the aim of numerous studies. This paper presents a comprehensive review of the recent developments and applications of UTHPs for thermal management of electronics. The different types and applications of UTHPs are introduced, and the packaging technologies of UTHPs are summarized and compared. Furthermore, the fabrication methodology and heat transfer characteristics of various wick structures used for UTHPs are reviewed and analysed in detail. Finally, the challenges affecting the development and application of UTHPs are outlined, and recommendations for future research are presented.

1. Introduction

With the rapid development of microelectronic technology and the telecommunication industry, a variety of electronic devices, particularly ultra-slim mobile devices such as smartphones or tablets, are being developed with focus on high performance, light weight and miniaturisation. This results in the fabrication of high-power electronic chips with high heat flux in a limited heat dissipation space. The development of mobile phones is the most relevant example of this. As shown in Fig. 1, the power consumption of the CPU processors for smartphones has been increasing constantly in recent years. Qualcomm® Snapdragon™ 820, 835 and 845, which are the three most successful CPU processor employed in smartphones in the last two years, exhibit full-load power consumptions of 3–5 W [1]. However, the space for heat dissipation is gradually reducing owing to the need for lighter and thinner smartphones [2], as depicted in Fig. 2.

In the absence of efficient thermal control methods, high power and highly integrated electronic chips would cause a substantial increase in the heat generation per unit area of a device. Moreover, a large heat flux is enclosed in a thin package, which is significantly beyond the limits of traditional air convection cooling [3]. A harsh thermal environment can deteriorate the usability and operational reliability of electronic components. Therefore, developing high-performance thermal management solutions to cool high-power, compact electronic devices are urgently required [4–6]. In recent years, graphite sheets, which exhibit high in-plane thermal conductivity (1600 W/m·K), have

* Corresponding author.
E-mail address: ytang@scut.edu.cn (Y. Tang).

https://doi.org/10.1016/j.apenergy.2018.04.072
Received 21 January 2018; Received in revised form 24 March 2018; Accepted 26 April 2018

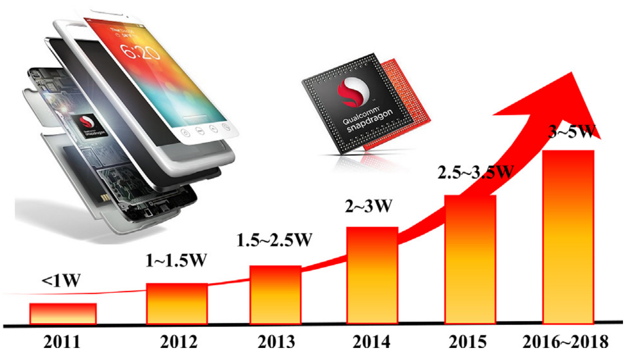

Fig. 1. Power consumption of CPU processors of mobile phones.

Fig. 2. Variation in thickness of SAMSUNG smartphones.

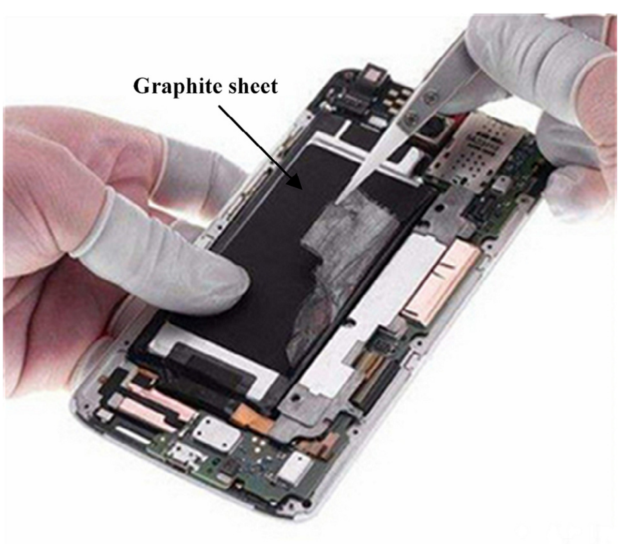

Fig. 3. Graphite sheet used for cooling mobile device [7].

been used in combination with a metal plate (Mg, Al, SUS, Cu, etc.) to cool mobile devices, as shown in Fig. 3. The small thickness (0.017 mm) of the graphite sheet renders it particularly suitable for heat dissipation of ultra-slim electronic devices. However, this solution has limitation for high heat dissipation as well as the cost of the graphite still remains a bottle neck when considering the high volume production [7].

As efficient two-phase heat-transfer devices, micro heat pipes have been widely used in the thermal control of high power density electronic components because of their remarkable thermal performance and high reliability. They have become a highly preferred solution and the main method for heat dissipation from common electronic devices such as desktop computers, laptops, spacecraft components and LED

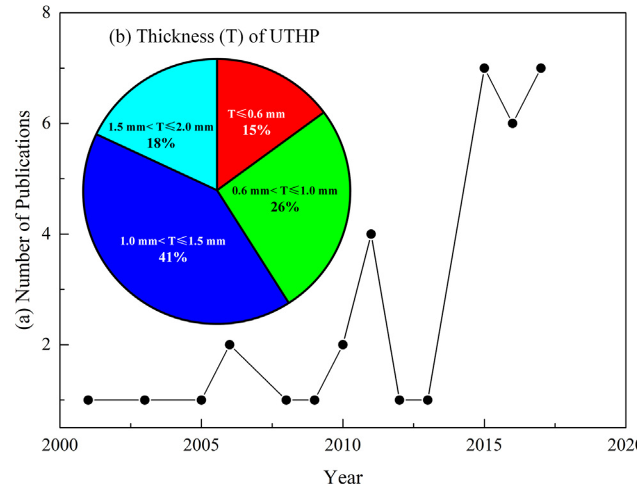

Fig. 4. Worldwide research effort on UTHPs over last 20 years: (a) Number of publications per year and (b) Thickness of UTHP.

modules, to provide temperature uniformity and eliminate local hot-spots generated in such devices [8–13]. However, with electronic devices having become highly integrated, lighter and thinner, the limited space significantly restricts the size of the thermal control components. This makes the conventional micro heat pipes, including cylindrical and flat-plate heat pipes, incapable of satisfying their usage requirements. To address the development requirements of mobile electronics, an ultra-thin micro heat pipe (UTHP) has been proposed and extensively investigated and applied [14–16]. Fig. 4 summarizes the worldwide research on UTHPs over the last 20 years. As is evident from Fig. 4, the number of publications on UTHPs increased rapidly over the last three years (Fig. 4(a)), and much of the research in the field of UTHPs has focused on the thickness range 1.0–1.5 mm (Fig. 4(b)). However, as the smartphone develops and becomes popularized rapidly, UTHPs with thicknesses below 0.6 mm have become the current research focus.

The rapid development of UTHPs has provided a highly efficient method to cool electronic devices with high power density and limited heat dissipation space. However, till date, there has been no review of the applications and development of UTHPs for electronic cooling. The objective of this literature review is to outline the worldwide research effort on UTHPs and provide the reader with a better understanding of the current development status and applications of UTHPs as well as guide its future designs and applications. In the first part of this review, the different types and applications of UTHPs are introduced. The second part summarizes the packaging technology of UTHPs. Various wick structures used for UTHPs are reviewed and analysed in the third part. Finally, the challenges affecting the development and application of UTHPs are outlined, and recommendations for future research are presented.

2. Applications and types of ultra-thin heat pipes

In practical production applications, UTHPs are defined as micro flat-plate heat pipes with an overall thickness of less than 2.0 mm. UTHPs are particularly suitable for the heat dissipation of ultra-slim portable electronic devices because they are thin and can fit closely on the surface of electronic components [7,14,17]. Thus, they are widely used in mobile and wearable electronic devices such as smartphones, notebooks and smartwatches, as illustrated in Fig. 5. However, different electronic devices require UTHPs with different thicknesses and heat transfer capacities. The thicknesses of UTHPs used for notebooks and tablet PCs are 1–2 mm and 0.8–1.2 mm, respectively, and their heat transfer capacity should be higher than 20 W. Moreover, for smartphones or smartwatches, the thicknesses and heat transfer capacities of the UTHPs are 0.4–0.6 mm and over 5 W, respectively. At present,