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Interface engineering to enhance thermal contact conductance of evaporators in miniature loop heat pipe systems

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HIGHLIGHTS

- The mLHPs have received attention from academic and industrial communities.
- But the complicated fabrication and system integration lead to high cost devices.
- Thus these have stunted the advent of commercialization.
- We introduce a novel low-cost sintering method for fabricating evaporators.
- The mLHP with new evaporator can provide overall cooling at a lower temperature.

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ABSTRACT

While miniature loop heat pipes (mLHP) have significant potential for electronic cooling, they are only used in a narrow niche of applications, such as space or military. Complicated fabrication and system integration leading to high cost devices are the main culprit. To this end, this paper explores a low-cost sintering method for fabricating evaporators for mLHP that have increased heat transfer performance. Through this method, the porous wick of the evaporator is fabricated to partially fill the vapor collection channels embedded in the base plate of the evaporator. The sintering method employs an organic material used to define the vapor collection channels, which is sublimated at the end of the sintering process. Interpenetrating these two, otherwise distinctive, parts of the evaporator results in an increased contact area and thermal conductance. The heat transfer performance of an mLHP employing the new evaporator is compared to that of a system using a standard evaporator configuration, where the porous wick is rested against a flat base plate. It is found that the thermal contact conductance increases about 25%, depending on the applied heat load, while the total thermal resistance of the mLHP with the new evaporator decreases approximately by a factor of two.

1. Introduction

Active cooling heat sinks combined with conventional heat pipes have been traditionally used in personal computers (PC) to efficiently control the temperature of multi-core central and graphic processing units (CPU and GPUs). However, in high-end computers and PCs with CPU over-clocking, the cooling capacity must be over 130 W, pushing the limits of existing cooling technologies [1]. In this context, miniature loop heat pipes (mLHP) are receiving increased attention from academic and industrial communities, being explored as potential candidates for electronics' cooling.

The mLHP consists of an evaporator, a condenser, vapor and liquid transport lines as in the conventional heat pipes, but differs in having a porous wick only within the evaporator [2]. This unique feature of the mLHP allows the separation of heat absorption and rejection sites, enabling the fitting of the small evaporator inside the confined space of modern PC [3]. The condenser can be placed away at a relatively large distance from electronics box, since fluid transport is ensured by ordinary tubes that can be easily bent. All these unique

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features make mLHP an attractive cooling alternative in a market where miniaturization is more important than ever [4–6].

To understand the challenges associated with mLHP, its operation principle, shown in Fig. 1, is briefly reviewed here. The heat dissipated by CPU is transferred through the evaporator base to the liquid-infiltrated porous wick, where the phase change occurs. The generated vapor is collected inside the vapor removal channels built into the evaporator and moved toward the condenser along the vapor transport lines. Following the heat rejection and phase change in the condenser, the liquid returns to the compensation chamber of the evaporator, from where is taken up by porous wick by capillary forces. The driving force in the flow loop is provided entirely by capillarity.

To better understand some of the challenges associated with operating a mLHP at steady state, let's inspect the diagram of the thermodynamic cycle shown in Fig. 2. Points 1–8 shown in the diagram correspond to the physical locations along mLHP system as illustrated in Fig. 1. The pressure drop, ΔP_{1-7}, in the loop from the evaporating to the absorbing surface of the porous wick results in a change in the saturation temperature between points 1 and 7:

$$\left(\frac{\mathrm{d}P}{\mathrm{d}T}\right)_{T_s} \Delta T_{1-7} = \Delta P_{1-7} \tag{1}$$

where the slope of the $(\mathrm{d}p/\mathrm{d}T)_{T_s}$ is the derivate that characterizes the slope of the saturation line at a given mean temperature, T_s, taken as the average temperature between points 1 and 7.

This pressure difference is the main driving force, counteracting all pressure losses in the system's components except of wick. Due to the current trend in miniaturization, the reduction in the size of the evaporator leads to a shorter distance between the two points (1 & 7). This enhances the heat leakage from the source to the CC, increasing liquid's temperature and contributing to a decrease in ΔT_{1-7}, which is detrimental to system function. In an attempt to solve this problem, wicks of low thermal conductivity have been proposed [3]. The drawback of this solution is that the conduction thermal resistance associated with the wick may become too large, resulting in excess parasitic heat leakage from the heat source to the liquid in CC through the lateral walls of the evaporator. The parasitic heat transferred to the CC causes an increase in the temperature of the liquid, which ultimately contributes to an increase in the loop operating temperature of mLHP and to a rise in the vapor mass flow rate in the evaporator. Therefore, these results lead to an increase in the vapor fraction inside the mLHP that increases the loop saturation pressure as shown in Fig. 2 and ultimately the operating temperature of the evaporator.

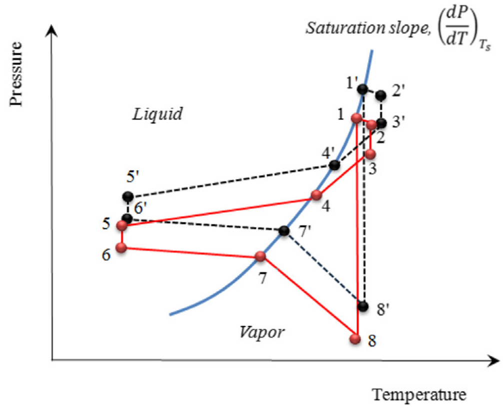

Fig. 2. Pressure versus temperature inside an mLHP at locations 1–8 shown in Fig. 1. The temperature rise of the liquid in the compensation chamber contributes to an increase in the overall operation temperature of mLHP as shown by dashed pressure–temperature curves.

The parasitic heat losses through the evaporator's walls may, however, be reduced if the thermal contact resistance between the porous wick and the evaporator base is decreased [7]. To engineer thermal contact resistance, one approach was to devise a new evaporator design significantly departed from the traditional configuration shown in Fig. 1, where vapor removal channels were located away from this interface [9]. While the system showed increased performance and relatively stable startup, the relatively high cost associated with the multiple step manufacturing process of the evaporator could hinder its widespread use in commercial applications.

In this paper, a new method for reducing the thermal contact resistance was explored. This method employs a configuration

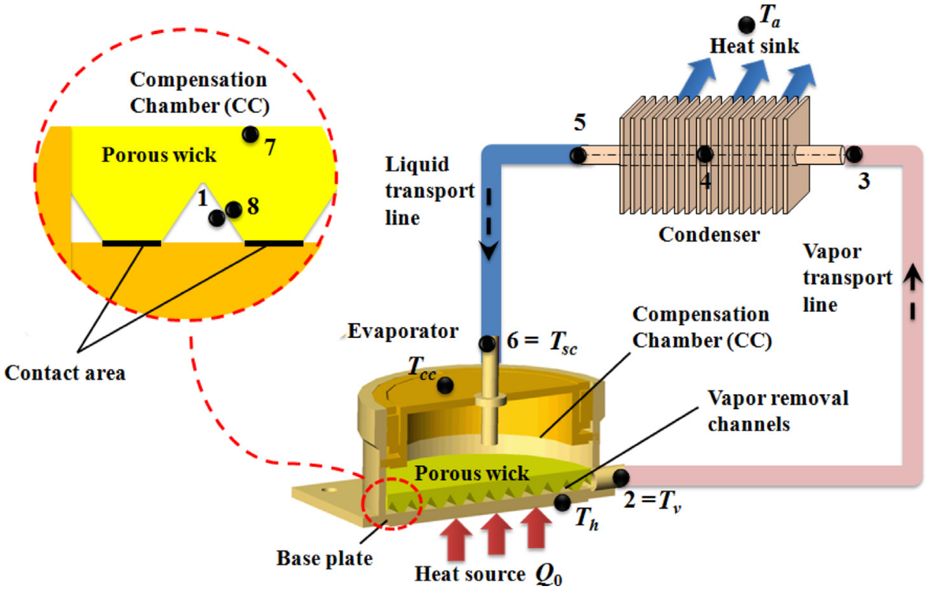

Fig. 1. Schematic of mLHP showing the cross-section of an evaporator with a standard wick configuration (i.e. porous wick rested against a flat base plate). Inset shows the details of the wick/base plate interface.