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# Fabrication and thermal performance of porous crack composite wick flattened heat pipe

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## HIGHLIGHTS

- This study developed a novel porous crack composite wick flattened heat pipe.
- Phase change flattening technology was proposed to form mode I cracks and fabricate composite wick.
- Start-up performance, isothermal performance, heat transfer limit and thermal resistance were investigated.

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## ABSTRACT

A novel porous crack composite wick flattened heat pipe (short for PCHP) was developed for the cooling of micro chips. PCHP was fabricated from grooved-sintered wick cylindrical heat pipe (short for GSHP) by phase change flattening technology. Porous crack composite wick consisted of micro crack channels at the unbending section and porous sintered powder. Micro crack channels were mode I cracks formed during phase change flattening process. Thermal performance of PCHP such as start-up performance, isothermal performance, heat transfer limit and thermal resistance was investigated by experiments. It was found that PCHP was able to achieve its steady state in about 30 s. The maximum temperature difference between evaporation section and condensation section of PCHP was less than 0.5 °C when the input power was about 10 W. The heat transfer limit of PCHP was highest about 50 W at cooling water temperature of 50 °C compared with grooved wick flattened heat pipe (short for GHP) and sintered wick flattened heat pipe (short for SHP). The thermal resistance of PCHP was a medium value between GHP and SHP.



## 1. Introduction

Nowadays, two notable characteristics exist in the heat dissipation of micro chips: high heat flux (almost $10^6$ W/m$^2$) and limited heat dissipation space (the power dissipation of CPU may be beyond 115 W in 1.5 cm × 1.5 cm area) [1,2]. The traditional forced convection cooling is close to its limit and temperature regulation problem of high heat flux micro chips is urgent to be solved. Heat pipe based on phase change now becomes an effective component for IC cooling due to its high heat conductivity, fast thermal response, good isothermal performance, high reliability, small size and no need of extra electric power [1,3].

Heat pipe is usually composed of three basic components: wick, working fluid and wall. Wick structure is the key factor that greatly influences the thermal performance of heat pipe. The wick mainly has three functions: supplying the necessary capillary driving force to maintain a closed circulation of working fluid and thus facilitate heat transport; providing enough room for liquid–vapor phase change including evaporation and condensation; exchanging heat between liquid–vapor and inner wall. Nowadays, grooved wick heat pipe and sintered wick heat pipe are used most frequently in the electronic cooling field. The grooved wick has high liquid permeability, yet limited capillary pumping ability while these prosperities of sintered wick are opposite [4,5]. A heat pipe with good thermal performance should guarantee that the wick has both high capillary pumping ability and high liquid permeability. However, it is difficult due to contradiction between high capillary ability and high permeability. Thus, how to balance between

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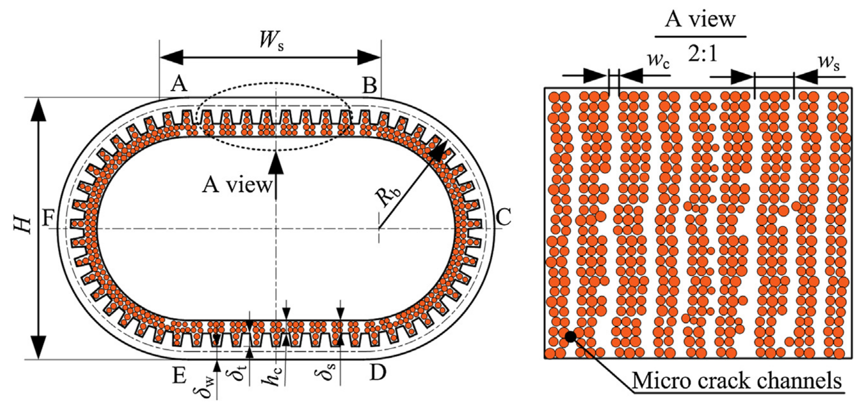


**Fig. 1.** Porous crack composite wick.

capillary ability and permeability of wick becomes a research focus and composite wick has potential to achieve this goal.

The optimal design and fabrication purpose of composite wick is to enhance or balance capillary ability and permeability to improve heat transfer limit of heat pipe. Solid state sintering method was usually used to fabricate composite wick. Vityaz et al. [6] first used the biporous media as heat pipe wick. The biporous wick structure was formed with the oxidation of copper particles as the second porous structure. It was found that the oxidized wick transferred five times of heat flux as the non-oxidized wick did. North et al. [7] formed a biporous structure by sintering clusters of copper powder or nickel powder together. Experiment results showed that the heat dissipation capability of biporous wick was six times more than the comparable monoporous wick. Wang et al. [8] proposed the triangular groove in the heat pipe covered by sintering a thin fine porous layer on the groove surface. The wick could not only improve the capillary force, but also extend the evaporating surface with high thermal performance. Hwang et al. [9] sintered modulated wick in heat pipe by using rectangular-shaped mandrels. The modulated wick was comprised of periodic stacks and grooves over a thin and uniform wick. The wick provided extra cross-sectional area to enhance axial capillary liquid flow and extend extra evaporation surface area with a moderate increase in conduction resistance of wick. Franchi [3] fabricated a composite wick by solid state sintering fine metal powder onto the layers of coarse pore copper mesh. The wick structure enhanced evaporation heat transfer at the liquid/vapor interface and the extension of the capillary limit. Tang et al. [10–12] and Li et al. [13] fabricated sintered-grooved wick by sintering copper powder in or over grooves. Experimental results showed that composite wicks enhanced both the permeability and capillary force compared to sintered wicks, and exhibited much larger capillary pressure than grooved wick. In summary, researches on fabrication and thermal performance of composite wick heat pipe are relatively few. The thermal performance of composite wick heat pipe was usually higher than that of monoporous wick. Thermal performance of optimized composite wick can be enhanced by increase or balance of capillary pressure and permeability.

A novel composite wick heat pipe was proposed to enhance miniature of flattened heat pipe. The composite wick was comprised of porous sintered powder structure and axial micro crack channels as shown in Fig. 1. This composite wick was defined as porous crack composite wick and its heat pipe was named as porous crack composite wick flattened heat pipe. PCHP was fabricated from grooved-sintered wick cylindrical heat pipe [14] by phased change flattening technology [15]. Micro crack channels of composite wick were formed in phase change flattening process. The composite wick and its fabrication process have not been reported in any previous research. This composite wick satisfied high thermal performance needs that were combined with the advantage of high capillary due to porous sintered powder, and high permeability and low flow resistance due to micro crack channels. Flattened heat pipe had relative small size and large thermal contact area between flattening surface and micro chips, which satisfied the cooling design for micro chips in limited space. The fabrication process of PCHP was also simple and low cost. Therefore, PCHP was suitable for industrialization production and had a brilliant commercial prospect.

## 2. Fabrication of PCHP

### 2.1. Fabrication process

Pure copper pipe and 200 mesh spherical copper powder were selected as raw materials to fabricate PCHP. The main fabrication processes could be concluded as shown in Fig. 2. Firstly, grooved pipe was plastically formed from copper pipe by oil-filled high-speed spin forming method described in our previous papers [16–18]. Tear number of grooved wick pipe was 55; secondly, spherical copper powder was sintered in grooved pipe as grooved-sintered wick at 950 °C for 3 h by solid state sintering method in another authors' another paper [19]. The grooved-sintered wick thickness

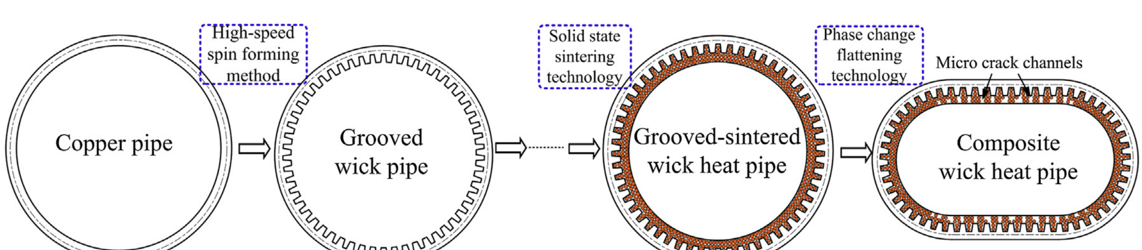


**Fig. 2.** Main fabrication process of PCHP.