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The performance of the vapor chamber based on the plant leaf

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ABSTRACT

The performance of a novel vapor chamber based on the leaf vein system is tested in this study. In this vapor chamber, the conceptual structure, being composed of leaf-vein-like fractal network and micro fin-pins and used to simulate the transportation principle of plant leaf, is made on the inner surface of the top copper plate to form the wick of the condenser. To the inner surface of the bottom, a copper plate sintered with a layer of porous wick is used as the evaporator. Because the conceptual structure is not restricted by the shape, the vapor chamber is made into circular and rectangular shape respectively. In the circular vapor chamber, the supporting columns sintered with copper powder are used to strength the vapor chamber. However, in the rectangular vapor chamber, the wick of the condenser contacts directly with the wick of the evaporator so as to strength the vapor chamber and shorten the back flow length of the liquid condensed on the groove surface. In the circular vapor chamber, the fractal angle of the leaf-vein-like fractal network is 30–70°, and the vapor chamber is packaged with eight bolts for convenience. In the measurement, the vapor chamber has small thermal resistance when the fractal angle is 40° and 50°, and in the rectangular vapor chamber, the thermal resistance of the vapor chamber is about 0.06 °C/W.

1. Introduction

Vapor chamber, as an efficient cooling device, composed of evaporator, condenser and wick, has been widely used for the heat dissipation in the photoelectric field. However, a challenge still exits, that is how to develop an excellent vapor chamber to meet the needs of the electronic device for cooling due to the large increasing heat fluxes encountered. Usually, the vapor chamber is directly installed on the electronic equipment for cooling. The heat from the heat source conducts to the evaporator and causes the working fluid to evaporate into the gaseous form, which is condensed further, and releases the heat. In the process, the heat is taken away by heat sink under forced air cooling or water cooling from the condenser. In other words, vapor chamber is a phase change cooling device that utilizes the latent heat of the working fluid to achieve high heat transport efficiency.

In the vapor chamber, the working fluid is transferred by the capillary pressure of the wick, which means the larger the capillary pressure is, the better the working-fluid flows. However, larger capillary pressure of the wick will lead to larger flow resistance (small permeability), which poses a challenging work for engineers to design a novel wick providing both big capillary pressure and high permeability. Generally, the wick is formed by 3 patterns, namely the sintering copper powder, copper mesh, and grooves. Among the three patterns, the sintered powder wick could provide the largest capillary pressure but minimum permeability, but the groove wick with the largest permeability and minimum capillary pressure, and copper mesh with moderate permeability and capillary pressure [1]. Therefore, it's difficult for a single structural wick to provide both the larger permeability and capillary pressure simultaneously, which evokes more researchers' interest to study the composite wick.

Chen et al. [2] studied a novel wick sintered by diamond and copper powder, in which the diamond and the powder were used to provide the channel for working fluid flow, as well as the capillary pressure respectively. Experimental results showed that the vapor chamber with the novel wick could increase the efficiency of the thermal conductivity, decrease the thermal resistance and exhibit excellent uniform temperature distribution on the top surface of the condenser. Semenic et al. [3] measured a bi-porous wick, in which the bigger pore was used to provide channel for working fluid, and smaller pore was used to provide capillary pressure. The measured results showed that the vapor chamber could receive heat density of 1000 W/cm^2. Moreover, the thicker the

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wick was, the bigger the heat density would be for the evaporator to transfer the heat happened at the interface of the gas and liquid. And there is a linear relationship between the permeability and the particle size of the copper powder [4]. Huang et al. [5] sintered powders on the big pores of a copper plate to obtain big capillary pressure and permeability to enhance the heat transfer. The results showed that the heat conduction coefficient was improved by 400% more than the single mesh wick.

Wang et al. [6] sintered the copper powders on the groove to form the wick, and found that the heat flux was improved by 3 times more than traditional wick structure. Franchi et al. [7] sintered nickel powders on the metal mesh to form a novel wick, in which the mesh was used as channel for working fluid flow, and the copper powder was used for providing capillary pressure. The results showed that the number of the screens would affect the heat transfer limit. Weibel et al. [8] sintered copper powders on the carbon nanotubes to improve the permeability of the wick made from carbon nanotubes. Ji et al. [9] arranged the fins to form microchannels for working fluid flow and at the same time sintered some copper powders on the fins to provide the capillary pressure, and the results showed that the vapor chamber could obtain smaller thermal resistance without dryout. Zhao et al. [10] proposed a novel concept for adaptive vapor chamber by using a thermo-responsive polymer coating to enhance the heat transfer and reduce local thermal gradients, and the results showed that the hotter surface became wetter, and smaller contact angle at higher temperature could generate larger capillary forces, which is the key factor of the adaptive vapor chamber. Based on those research results, they further presented a biomimetic electrospray vapor chamber including a beetle-inspired super hydrophobic condenser with hydrophilic bumps, on which the working fluid accumulates [11]. In brief, all studies mentioned above aimed at the same target to improve the performance of the vapor chamber through increasing both the capillary pressure and the permeability. In our early study [12], it was suggested that both the capillary pressure and the permeability could be possibly improved by studying the heat dissipation mechanism of plant leaf.

Heat dissipation is essential to plants, especially to those living in the arid environment to survive due to the thermal shock of high temperature. Botanists believed that heat dissipation of the plants is composed of physiological process and non-physiological process. The physiological process refers to the photosynthesis of plants, in which the energy consumed is only 1–2% of the overall energy absorbed by plants [13]. Therefore, about 98% energy of plants is consumed by non-physiological process, namely the evaporation, radiation and convection. Penman [14] established the model of energy balance about the evaporation of plants, based on which, Ye et al. [15] induced the radiation into the penman model and found that as an efficient cooling method in the non-physiological process, the evaporation was very important in the cooling of plants, since about 32.9% of the overall heat is dissipated by evaporation in summer. For some tall plants, because the dimensions of the cell wall matrix are of the order of 5 nm, a large capillary pressure about 30 MPa can be provided to transport water. Furthermore, from the viewpoint of natural evolution, plant leaf can be regarded as the optimized structure that could provide a large permeability as well, which might evoke engineers to design a novel vapor chamber.

Over the past decade, researchers tried to optimize the mechanical structure based on plant leaf [16–18]. Especially to help improve the performance of the cooling device, many researchers studied the use of a fractal-like branching network which mimics the flow distribution patterns found in nature [19–23]. However, the fractal tree-like networks of these studies were mainly used in heat sinks (an external power needed) rather than in a vapor chamber. Based on the cooling principle and excellent structure of plant leaf evolved for millions of years, our group have established the model of leaf-vein-like fractal network and analyzed its performances in capillary pressure and permeability, and found that the leaf-vein-like fractal network could provide both big capillary pressure and big permeability [12]. Based on the principle of transportation of plant leaf, a conceptual structure composed of leaf-vein-like fractal network and porous structure was proposed further, in which the leaf-vein-like fractal network was used to simulate the leaf vein, and the porous structure was used to simulate the mesophyll tissue. The results showed that the conceptual structure had better flow performance than the traditional structure [24]. Later on, in the experiment of the conceptual structure being used as the wick of vapor chamber, it was proved that the structure based on the transportation principle of the plant leaf could provide both small thermal resistance and high temperature uniformity [25]. In this paper, the influence of the fractal angle on the cooling performance of the conceptual structure is investigated in the first place. In order to prove the conceptual structure is not only used in circular vapor chamber but also works efficiently use in rectangular, the investigation the performance of the conceptual structure used in the rectangular vapor chamber is made.

2. The vapor chamber design

2.1. The circular vapor chamber

In order to investigate the influence of the fractal angle on the cooling performance of the vapor chamber, the wick was manufactured with different fractal angle θ (i.e. 30°, 40°, 50°, 60°, 70°, shown in Fig. 1a). The length of the first level channel of the leaf-vein-like fractal network L_0 is 12 mm, the width of the first level channel W_0 is 0.38 mm, the length ratio defined as $l = L_{k+1}/L_k$ is

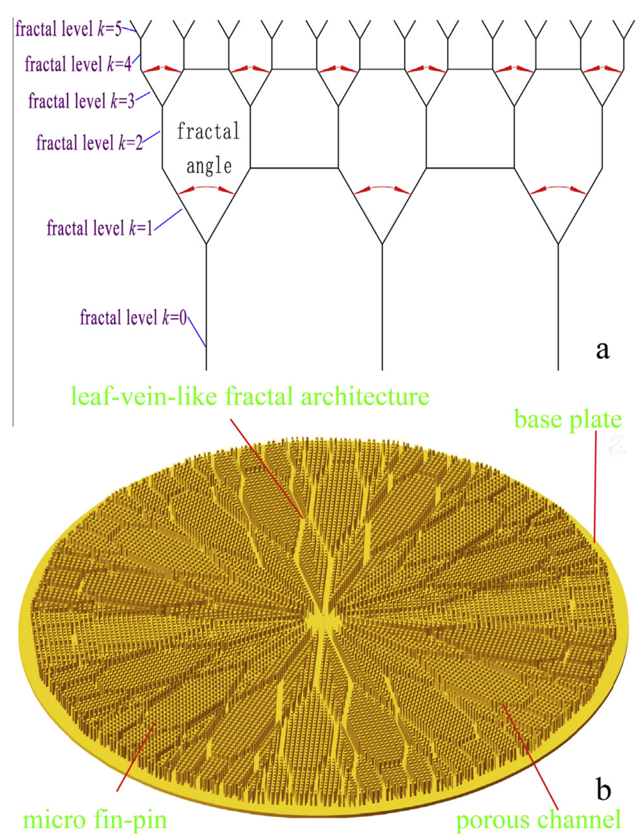

Fig. 1. Condenser design: (a) leaf-vein-like fractal architecture; (b) condenser model.