Research progress on heat dissipation technology of vapor chamber

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Abstract. Vapor chamber is a new type of two-phase flow heat dissipation technology. It offers the benefits of excellent thermal conductivity, uniform and consistent temperature, and the ability to reverse heat flow direction. It addresses the limitations of conventional heat pipes, such as limited contact area, high thermal resistance, and non-uniform heat flow. In the future, it will be an effective solution for cooling high heat flux electron devices in the electronic industry. This paper summarizes three types of wicks: micro-channel, sintered powder, and sintered screen. This article contrasts the benefits and drawbacks. This brief overview illustrates the latest advancements in heat and mass transfer theory related to vapor chamber, both domestically and internationally. Scholars employ the boiling theory of transport modelling to capture the gas-liquid interface, ascertain the critical heat flux, and analyze the flow and heat transfer laws of the working fluid in the uniform temperature plate. This paper analyzes several factors that affect the performance of the uniform temperature plate, including the selection of fluid, filling rate of liquid, size and distribution position of heat source input power, and working angle. Finally, this study analyzes and forecasts the practical applications of vapor chamber, taking into account the surrounding environmental factors.

1. Introduction

In recent years, electronic components are increasingly showing the trend of miniaturization and high power consumption. How to solve the problem of performance degradation of electronic components due to high heat generation has attracted widespread attention. Heat pipe two-phase cooling equipment has become an efficient heat transfer device due to the large thermal conductivity produced by the phase change. With the continuous expansion of the application field of heat pipe cooling technology, people have manufactured a variety of special-shaped heat pipes according to the requirements of some special occasions, such as pulsating heat pipes, loop heat pipes (LHP), capillary pump suction two-phase loop heat pipes (CPL) and various micro-heat pipes [1-4]. Since the surface of many devices is flat, in order to meet such devices, in 1969, Sheppard first designed a heat pipe with rectangular cross-section to cool the baseplate of integrated circuits. On the basis of this research, Feldman proposed vapor chamber. The working fluid can realize circulating flow in a closed space. Subsequently, vapor chamber is widely used in microelectronics devices, space thermal control and other fields.

Vapor chamber includes closed chamber, capillary structure, and working fluid, for uniform temperature distribution. In order to ensure that vapor chamber has efficient heat transfer performance, the shell is usually made of materials with high thermal conductivity, and the inner wall is surrounded by a liquid suction core. In order to meet the demand of pressure resistance, some vapor chambers are designed with solid column, sintered column or attached to the outer surface of solid column suction core to form sintering ring. At present, vapor chamber has been used in some high performance commercial and military electronic devices. With the development of processing technology, vapor chamber is developing in the direction of getting thinner and thinner.

2. Structure and performance of liquid absorbing core

Vapor chamber relies on the internal suction core structure to provide the power of condensate reflux, which affects the critical heat flow and thermal performance. In order to make it have better heat transfer characteristics, new micro-absorbent core structures have been continuously developed. The surface treatment of absorbent core significantly enhanced the comprehensive performance of vapor chamber. There are three kinds of common absorbent core structures [1]: micro-channel type, sintered powder type and sintered wire mesh type.

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2.1 Microfluted suction core

Groove suction core is made of grooves of various shapes processed on the inner wall of uniform temperature plate. However, the preparation of microcell liquid absorbing core is a technical difficulty, but great progress has been made in recent years. He [2] used diffusion welding layered solid manufacturing technology to obtain deep and narrow slots with small deformation that could be welded in one time. The thermal conductivity can reach a maximum effective value of 2552.2 W/(m·K).. Chen [3] used femtosecond laser processing to obtain microgrooves with good quality and a depth-width ratio of 5.4.

In order to solve the problem of limited heat transfer of the small capillary limit of the microgrooves, many new structures have been developed on the basis of common microgrooves. Hung [4] designed the star-shaped channel suction core, as shown in Figure 1. Bahmanabadi [5] studied the thermal resistance of new rectangular grooves, as shown in Figure 2. The grooves were found to enhance heat transfer by inducing rotational motion. Li [6] divided the disk into a series of identical fan regions. Inspired by the natural branching phenomenon, a new growth model was developed, as shown in Figure 3.

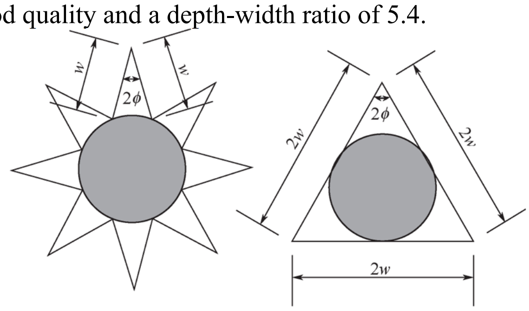

Figure 1. Star channel and triangular channel

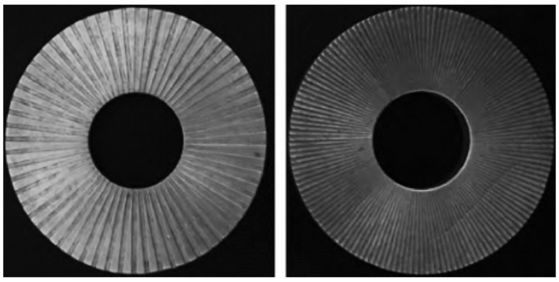
Figure 2. Radial rectangular slots and radial inclined triangular slots

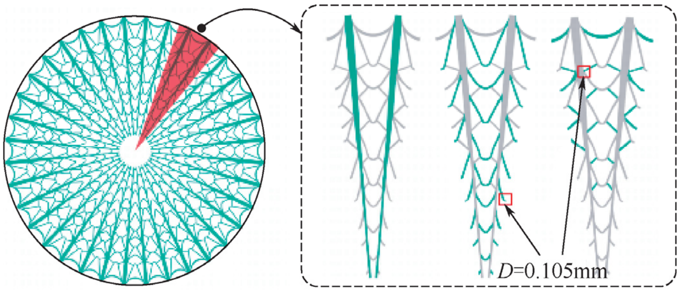

Figure 3. Natural branching microchannel structure

2.2 Sintered powder

Sintered metal powder porous material has the advantages of light weight, high capillary force. Sintered powder, as a traditional liquid absorbing core structure, is widely used in heat pipe and vapor chamber. Its manufacturing process is constantly optimized, especially the filling process which directly affects the structure quality of capillary suction core. Powder filling equipment is gradually improved in the direction of precision and automation, including the research on vibration parameters [7], powder quantitative filling and vibration powder filling equipment. For sintering process, it is very important to control sintering time and temperature.

For single-pore sintered capillary core, particle diameter, porosity and thickness of sintered powder have great influence. Li [8] constructed a tapered capillary core based on the principle of bionics and velvet taro as the design basis. The two tapered structures are shown in Figure 4.

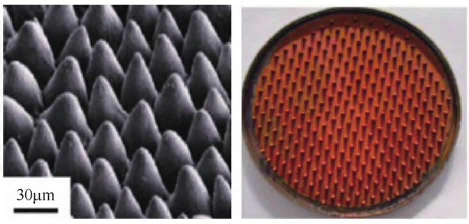

Figure 4. Two conical structures

In addition to single-pore suction cores, a variety of multi-pore suction cores with different particle sizes and mixed materials have been proposed, especially dual-pore cores, which have excellent performance and have been widely used in vapor chamber [9]. Wang [10] made porous cores from different metal powders in the shape of balls and sticks, as shown in Figure 5. The effects of the mixing ratio o were studied.

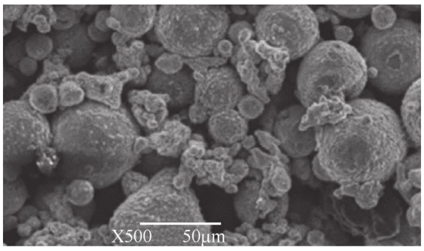

Figure 5. SEM image of nickel-copper composite porous suction core

2.3 Composite suction core

Composite suction core can be combined with the advantages of various kinds of suction core to achieve the overall optimal, such as multilayer screen composite, screen and powder composite, powder and groove composite. Chen [10] proposed a multi-layer composite fine-mesh suction core, which was composed of different layers of coarse mesh and fine mesh. This can improve the hygroscopic performance of suction core.

3. Influence factors and related experiments

3.1 Working fluid

The selection of working fluid must take into account the compatibility between the liquid absorbent core and substrate material, as well as factors such as thermal stability, wettability, high latent heat, high thermal conductivity, high surface tension, and other relevant considerations. Vapor chamber is mainly used for internal chip heat dissipation of electronic equipment. It belongs to normal temperature heat pipe and usually uses water, methanol, ethanol, acetone and nano fluids. Patankar [7] provides a new method to minimize thermal resistance as the design goal. A simplified analysis of two fluid characteristic values is proposed.

With the development of nanotechnology and thermal technology, more and more attention has been paid to the research of using nanofluids to strengthen heat transfer. Nanofluids can effectively improve the hydrophilicity, contact angle and nucleation site number of the surface to achieve the purpose of strengthening heat transfer. The thermal conductivity of nanofluids increases with the increase of concentration, and the critical heat flux density will also increase. However, when the concentration of nanofluids exceeds the appropriate concentration, the aggregation of nanoparticles blocks the nucleation check point, making it difficult to nucleate and even worsen boiling heat transfer. The contact angle of nanofluids has a very important relationship with wettability. In general, the contact angle will decrease with the increase of the mass fraction of nanofluids, thus increasing the wettability of the surface, delaying the drying of the evaporation surface, and further strengthening the boiling heat transfer of nanofluids.

3.2 Liquid filling rate

Liquid filling rate is generally defined as the percentage in the total volume of the internal space of vapor chamber. A large number of literatures present that the optimal filling rate is closely related to the operating power, the geometry and material type of the radiator, and the internal structure.

A large number of literatures show that the optimal liquid filling rate corresponding to the minimum thermal resistance is closely related to the operating power, the geometry and material type of the radiator, and the internal structure of the temperature equalizing plate. However, there is always an optimal liquid filling rate for a specific temperature equalizing plate. From a microscopic point of view, when the liquid filling rate is low, the independence between evaporation and condensation is high, and the degree of mutual influence is weak. When the liquid filling rate is high, the frequency of bubble detachment is reduced, and the intensity of condensation and boiling heat transfer are suppressed to a certain extent. When the liquid filling rate is in an intermediate horizontal range, the rupture of the bubble causes a strong convection heat transfer between the evaporation surface and the liquid working medium, which promotes the boiling heat transfer. At the same time, the disturbance of the bubble rupture on the liquid surface causes the condensate film to be thinner, which strengthens the condensation heat transfer capacity.

3.3 Heat source

With the continuous increase of the power of electronic products, there are multiple hot spots on electronic devices. Vapor chamber is equivalent to multiple heat pipes connected in parallel. The location distribution of heat source is an important factor affecting the homogenization of vapor chamber.

The size of heating power and the size of filling rate have a great influence on the thermal resistance of the average temperature plate. In future research, they can be considered comprehensively. Under different circumstances, the influence of the heat source area on the average temperature plate is very different. The research believes that the thermal resistance of the average temperature plate is mainly composed of evaporation thermal resistance, condensation thermal resistance and flow thermal resistance. The effect of condensation thermal resistance is generally small and can be ignored. When the heat source area is small, the evaporation thermal resistance is large. As the fluid temperature rises, the vapor density increases, the viscosity decreases, and the vapor pressure loss also decreases, resulting in a decrease in flow resistance. In different temperature equalizing plates, the size of the heat source area has different degrees of influence on the thermal resistance of evaporation and flow, so the opposite conclusion may be obtained. Because the temperature equalizing plate has a small diffusion thermal resistance, it still maintains good temperature equalization even under uneven heat source distribution, which helps solve the hot spot problem. However, in practice, the separate arrangement of heat sources is conducive to reducing the maximum temperature and temperature difference and increasing the critical heat flux, and symmetrical arrangement should be adopted as much as possible.

3.4 Experimental summary

In recent years, scholars have verified the theoretical model through a large number of experimental. Table 1 presents a comparison of the heat dissipation characteristics of the temperature-averaging plate when employing various wick materials as reported in the literature. As can be seen from Table 1, copper is the most commonly used raw material of the liquid-absorbing core, and water is the most commonly used working fluid. The selection of the liquid-absorbing core structure and the working fluid will have a significant impact on the thermal resistance. The temperature-equalizing plate can withstand a large heat load, and the critical heat flux density can reach 800 W / cm^2 and above. Because the working fluid, the structure of the liquid-absorbing core, and the input heat flux density of the temperature-equalizing plate are different, it is very difficult to objectively evaluate the heat dissipation effect of various temperature-equalizing plates. However, compared with traditional heat pipes, it is undeniable that the temperature-equalizing plate has huge advantages.

Table 1. Summary of experimental research

Type of suction core	Liquid core structure	Working fluid	Heat source area/mm^2	Heat flux density/ W·cm^{-2}	Thermal resistance/ K·W^{-1}
Channel	Multi-tooth plough grooving	Acetone	1300	15.38	0.056
	Rectangular microslot	Water	10.24	103	1
	Radial triangular groove	Methanol	37.14	6.893	0.09
Sintered powder	Copper powder	Nanofluids	---	---	0.25
	Copper powder	Deionized water	---	---	0.3
	Conical copper powder suction core	Water	140	114.28	0.079
	Irregular subspherical copper powder	Water	225	560	0.24
Sintered screen	Copper mesh	Water	400	12.5	0.107
	Spiral wire mesh	Water	225	3.5	0.4
	Multilayer mesh	Water	100	198.6	---

4. Conclusion

Vapor chamber is an efficient device with high thermal conductivity and low thermal resistance. It can be seen from literatures that many studies have focused on reducing thermal resistance, improving heat transfer limit, and obtaining higher heat flux and uniform temperature performance. In the past 20 years, considerable advancements have been achieved in the theoretical, experimental, and numerical simulation studies. To gain a comprehensive understanding of the heat transfer mechanism in uniformly heated plate, it is essential to conduct thorough research in the following areas.

- It is necessary to establish a more perfect theoretical model, especially the phase transition heat phenomenon of boiling and condensation coexistence in the vapor chamber. In such a system, there is a complex coupling relationship between boiling - condensation - thermal conductivity. The three heat transfer processes interact, influence and restrict each other. To ignore the difference between them would inevitably bring great error and uncertainty.
- Innovative suction core structure. It is imperative to enhance surface modification mechanism research for micro-nano-layer structures in order to optimize heat transfer processes. Multi-objective optimization of heat source, working angle, liquid filling rate and other factors is carried out to improve the performance.
- The collapse mechanism of ultrathin needs further study.

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