Thermal Performance Simulation of Novel Micro Heat Pipe

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Abstract. In this paper, a mathematical model of micro-heat pipe module is established, and the thermal performance of micro-heat pipe module under different heating power and different heat conducting fins is studied by numerical simulation method. The simulation results show that the maximum temperature difference on the substrate surface of the micro-heat pipe is within 2.5 °C, and the micro-heat pipe can effectively diffuse the concentrated heat source and has excellent temperature uniformity characteristics at high heat flux. Further, the influence of heating power and heat conduction fins on the heat transfer performance of the micro-heat pipe module has been analyzed. It is found that the thermal diffusion performance of the micro-heat pipe module reaches the optimal when the heat flux density is 180W and the heat conduction fins are 20 pieces. Simulation shows that the micro-heat pipe module can avoid the thermal stress concentration of the substrate to the greatest extent, thus ensuring the efficient and stable operation of the power module.

1. Introduction
With the increasing power consumption and integration of electronic devices, when the equipment operates at high power, a large amount of heat energy will be generated. Heat accumulation will cause unstable and damaged system operation. Uneven temperature distribution will generate thermal stress inside electronic devices and lead to thermal deformation. About over 50% of electronic equipment affect working efficiency due to insufficient heat dissipation [1]. Therefore, the problem of heat dissipation has become the bottleneck for electronic equipment to achieve high efficiency and miniaturization. Efficient heat dissipation technology is the key to the development of microelectronic technology in the future.

In recent years, micro-flat heat pipes have been widely used in electronic component cooling, equipment lighting, power batteries and other aspects due to their light weight, flexible structure and good heat dissipation performance [2]. Domestic scholars have carried out comparative experiments on the micro rectangular channel structure of micro groove flat heat pipe under different heating power, liquid filling rate and cooling mode of condensing section [3, 4]. Xia Guodong and others [5, 6] studied the application of flat heat pipes in LED heat dissipation systems and analyzed the uncertainty of experimental results. Li Hongchuan and others [7, 8] applied hydrophilous plant blades to flat heat pipes to make bionic capillary cores in order to study their heat transfer performance. Cui Zhuo and others [9] analyzed and studied the flow and heat transfer mechanism in rectangular micro-channel flat heat pipe through visual experiments.
Domestic scholars have little research on the application of micro-flat heat pipe to CPU heat dissipation. The thermal resistance of the model is mostly measured by thermo-couples. In this paper, a micro-plate heat pipe radiator is designed with CPU chip as the research object, and the thermal resistance of the heat pipe is simplified by similar composite flat wall calculation. The influence of heat flux density and heat conducting fins on heat transfer characteristics is analyzed through numerical simulation, and subsequently, the heat dissipation optimization scheme for high-power integrated power module is proposed.

2. Establishment of Physical Model of Micro Heat Pipe Module
The micro-heat pipe uses the steam cavity inside the metal plate to transfer heat, with the edge of the cavity inside the heat pipe a rectangular micro-channel. The liquid working medium achieves phase change back-flow through the capillary force of the micro-channel. There are many factors affecting the heat dissipation capacity of the heat pipe in the phase change heat inside the heat pipe, such as the working limit, boiling limit and capillary limit, etc. [10]. Therefore, the equivalent thermal conductivity is introduced. In this paper, the equivalent thermal conductivity of micro-heat pipe is set to 40000 W/(m·K). According to the market radiator specifications, the model is simplified to a cuboid heat dissipation plate of 40mm × 24mm × 6mm. The CPU chip adopts a cuboid of 25mm × 20mm × 1mm, and assuming that the internal structure is integral and the physical properties in all directions are uniform. An air duct is set up to simulate the forced convection of air at the condensing end of the radiator. That's to say, extend the length of the inlet air duct by one time length of fins to ensure uniform distribution of the inlet speed, and extend the outlet air duct by five times length of fins to ensure no back-flow at the outlet. Figure 1 is a schematic diagram of a micro heat pipe module model.

![Figure 1. Micro heat pipe model.](image)

3. Numerical simulation and analysis of heat transfer characteristics

3.1. Selection of The Control Equation
The control equation of the heat source adopts the energy equation:

\[
\frac{\varphi}{\lambda} + \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) = 0
\]  

(1)

The control equations of heat pipes and heat conducting fins adopt energy conservation equation:

\[
\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0
\]  

(2)
The control equation of air flow field adopts momentum conservation equation:

\[ \rho \left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = -\frac{\partial P}{\partial y} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \]  (3)

3.2. Boundary Condition Setting
Since the output power and heat dissipation of the heat source are almost close to each other [11], the heat flux density on the bottom surface of the heat source is taken as the second kind of boundary condition. According to Reynolds number, assuming that the air duct fluid is in a three-dimensional laminar incompressible steady flow, Viscous chooses Laminar. The inlet air temperature is set to 298.15K ambient.

4. Analysis of Simulation Results

4.1. Temperature Distribution of Micro Heat Pipe
With a given air velocity of 3 m·s\(^{-1}\), the temperature of each measuring point is shown in Figure 2 at different heat source powers. It is found that the higher the thermal power is, the higher the temperature of the corresponding measuring point is. Measuring points 3, 4, 6 and 7 are respectively four points from left to right along the X-axis direction in Figure 2, and the temperature difference between the measuring points is within 2.5℃, indicating that heat can be uniformly diffused and transferred to the micro-heat pipe. The out-coming results from the fact that the micro-heat pipe can carry out radial mass transfer and heat exchange, as reduces the average temperature gradient of the contact part between the CPU chip and the radiator and the bottom part of the radiator, and decreases thermal resistance as well. The simulated result clearly shows that the temperature uniformity characteristic of the micro-heat pipe. The simulated result that the micro-heat pipe reaches a stable state after 340 seconds under working conditions explains that the micro-heat pipe has good fast starting characteristics.

![Figure 2. Temperature of measure point.](image)

4.2. Influence of Heat Source Power on Heat Transfer Performance
Figure 3 shows the influence of the heating power of the heat source on the heat transfer performance of the radiator when the air flow rate is 3 m·s\(^{-1}\). The highest temperature of the chip increases proportionally with the increase of the power. During the simulation process, the average temperature rise of the micro-heat pipe substrate is about 5℃ smaller than that of the copper substrate, and the temperature difference is the largest at 180W high heat flow input, reaching about 8℃.
Figure 3. Relationship between chip temperature and heating.

4.3. Influence of Heat Conducting Fin on Heat Transfer Performance

Figure 4 presents the influence of the number of heat conducting fins of the radiator on the chip temperature in the micro-heat pipe module. It can be seen from the figure that increasing the number of fins can reduce the highest temperature of the chip, and the thermal diffusion performance reaches the optimal when there are 20 heat conducting fins. This larger heat transfer surface area is beneficial to the reduction of the thermal resistance. However, the cooling effect caused by increasing the number of fins is no more obvious, indicating that the smaller fin spacing has effect on the boundary layer, which leads to the decrease of convective heat dissipation performance of air forced cooling. But compared with the increase of the height of fins which has little effect on reducing the temperature of the chip, the appropriate increase of the amount of fins can definitely improve the heat dissipation performance of the radiator.

Figure 4. Relationship between fin and chip temperature.

5. Conclusion

The micro-heat pipe module has good heat absorption performance, better isothermal property and fast start-up characteristics. The temperature difference among heat pipe measuring points is within 2.5°C, which can effectively diffuse the overall temperature of the power module. It is hoped that the rapid temperature homogenization of heat pipe can reduce the thermal resistance of the shell and provide conditions for integrated packaging with electronic components.
In the case of high heat flow impact, the micro-heat pipe module displays the characteristic of strong heat diffusion, and the micro-heat pipe has more obvious advantages for rapid cooling of the chip. To increase the number of fins can reduce the highest temperature of the chip. When the heating power is 180W and there are 20 heat conducting fins, the heat transfer effect of the radiator is the best.

6. References
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