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Research progress of microchannel single-phase flow enhanced heat transfer technology

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Abstract: With the miniaturization and high degree of integration of electronic devices, the heat generated inside them is difficult to be discharged in a timely manner, resulting in high temperature, performance degradation and even damage to the devices. The microchannel heat sink is characterized by its compact structure and large heat transfer coefficient, which makes it the most suitable device for heat dissipation of electronic devices, but there is still the problem of insufficient heat transfer capacity in the face of future heat dissipation of electronic devices with high heat flow density. This paper firstly gives a brief introduction to the microchannel heat transfer technology, and then summarizes the effects of changes in the geometry and cross-section shape of the microchannel on the heat transfer characteristics and pressure drop, and sums up the influence of the geometric parameters of the law, and also analyzes the effects of variable cross-section channels on the performance. Finally, summarizes the research progress of the bionic-based topology design, and points out that the current research on bionic microchannel structure is still in the stage of model simplification, and the topology design of microchannels described in the paper can all achieve the purpose of enhanced heat transfer. The results show that rectangular channels are easier to obtain and have better performance in practical applications, and the spiderweb-like structure has the best overall performance in topology design. Based on the limitations of the existing research on microchannels, this paper proposes a research direction to change the geometry of the bionic structure, which will provide a reference for the future heat dissipation problems of electronic devices with high heat flow density.

1. Introduction

With the miniaturization and high degree of integration of electronic devices, the heat flow density of electronic devices is increasing, and a long period of high-temperature working environment will cause overheating of electronic devices [1~2]. When the temperature of electronic equipment reaches 70~80℃, its reliability will be reduced by 5% for every 1℃ rise in temperature

[3]. According to statistics, 55% of electronic component failure is caused by high temperature [4]. In order to improve the reliability of electronic equipment and extend its service life, effective heat dissipation measures must be used. The traditional way of cooling electronic chips is air-cooled heat dissipation, but the air-cooled heat dissipation technology is only applicable to some scenarios with low heat dissipation requirements. The heat flow density of current chips can reach up to 100W/cm2, and the future ultra-large-scale integrated circuits may exceed 1000W/cm2 or even higher [5], so it is necessary to seek a new type of heat dissipation technology to meet the demand.

Microchannels, also known as microchannel heat exchangers, are heat exchangers with channel equivalent diameters of 10 to 1000 μm. Microchannel enhanced heat transfer technology is a technology used to enhance the heat transfer effect, microchannel heat transfer technology was first proposed by Tuckerman and Pease [6] in 1981 and achieved a heat dissipation density of 790 W/cm2 using single-phase heat transfer of water, the structure can effectively increase the contact area between the radiator and the heat transfer fluid, thus improving its heat transfer capacity. When the fluid flows through the microchannel, due to the small size of the channel, the contact area between the fluid and the solid wall is greatly increased, resulting in a significant increase in heat transfer performance. At the same time, the fluid flow speed in the microchannel is higher, the transfer time between the fluid and the wall is shorter, and the heat transfer efficiency is also higher. Microchannel heat sinks have been widely used in the cooling field of electronic components due to their compact structure and large heat transfer coefficient, and their structure is shown in Figure 1. However, the current research only focuses on the cooling of chips with a heat flow density of less than 100W/cm2, and its heat transfer capacity still needs to be improved. In recent years, scholars at home and abroad have carried out in-depth explorations on the geometry and flow channel arrangement of microchannels in order to improve the heat transfer efficiency and thermal uniformity of microchannels [7~9].

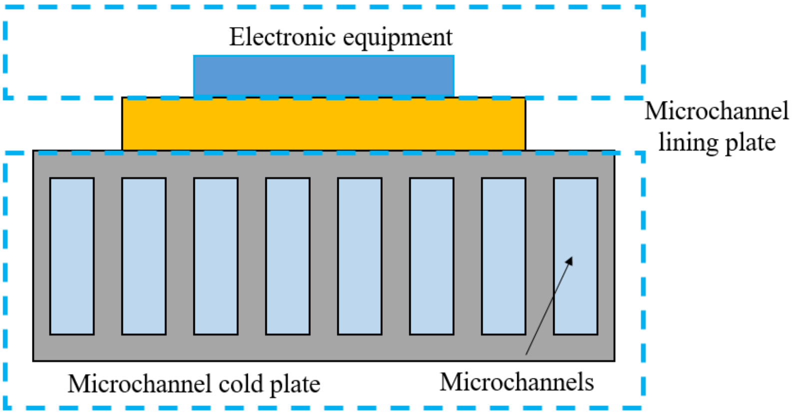


Figure 1: Microchannel heat sink structure.

2. Influence of geometric parameters on microchannel heat transfer

The performance of microchannel heat sinks is influenced by geometric parameters and cross-section shape, and the parameters for evaluating the heat transfer performance of microchannel heat sinks include convective heat transfer coefficient, Nussle number and thermal resistance, while the performance indexes for the work fluid flow of microchannel heat sinks include pressure drop and pump power [10]. The goal of improving the heat transfer performance of microchannel heat sinks is to increase the convective heat transfer coefficient and Nussell number and to decrease the thermal resistance, pressure drop and pump power. These objectives can be achieved by optimizing the geometrical parameters and cross-sectional shape of the microchannels, e.g., by changing the channel size, shape and structure to increase the surface area and to improve the flow characteristics.

2.1. Influence of microchannel cross-section size

The initial form of the microchannel is a rectangular cross-section flat channel, and the dimensions do not change along the flow direction.Liu et al. [11] investigated the flow heat transfer characteristics of rectangular microchannels with a cross-section aspect ratio of 0.375~1, and found that the cross-section aspect ratio is an important factor affecting their heat transfer performance. Increasing the cross-sectional aspect ratio can improve the local convective heat transfer coefficient and Nussel number in the channel, but the Nussel number does not increase infinitely with the increase of aspect ratio. Niu et al. [12] proved that when the aspect ratio tends to infinity, the Nussell number tends to a fixed value of 8.23. Wang et al. [13] used deionized water as a coolant to study the flow and heat transfer characteristics of the microchannel radiator, and found that when the cross-sectional aspect ratio is greater than 14.66, the local convective heat transfer coefficient inside the channel basically stays unchanged, and the further increase of the aspect ratio is not very effective in improving the heat transfer performance. The performance of rectangular microchannels is best in the range of 8.904~11.442. However, in the case of a rectangular microchannel with a constant equivalent diameter, with the increase of the aspect ratio, the pressure drop of the microchannel increases, and the flow resistance in the channel increases [14].

In addition to the aspect ratio, the hydraulic diameter is also an important factor affecting the performance of the channel.Jiang et al. [15] investigated the fluid flow characteristics of rectangular microchannels with hydraulic diameters ranging from 120 to 480 μm. The results showed that with the decrease of hydraulic diameter, the wet perimeter length and heat transfer area of the channel increased, which was effective in enhancing convective heat transfer, but the frictional resistance coefficient corresponding to the same Reynolds number increased. Jin et al. [16] analyzed and discussed the fluid heat transfer performance in a microchannel with an equivalent diameter of 100 μm and found that when the Reynolds number is the same, the drag coefficient increases with the increase of the equivalent diameter, while the Nussle number and the pressure drop decrease with the increase of the equivalent diameter.

When investigating the relationship between aspect ratio and microchannel performance, the cross-sectional area or channel width is often limited [17]. In this case, the hydrodynamic diameter decreases as the aspect ratio increases, making it difficult to determine the relative importance of the effects of hydrodynamic diameter and aspect ratio on the thermal performance. Sahar et al. [18] investigated microchannels when the aspect ratio was fixed at 1 and the range of hydrodynamic diameters was 100-1000 μm and when the hydrodynamic diameters was fixed at 560 μm and the range of aspect ratios was 0.39-10 respectively. The results show that when the aspect ratio is constant, the change of hydraulic diameter has no significant effect on the friction factor, and the Nussle number increases with the increase of hydraulic diameter; the effect of aspect ratio on the performance of microchannels when the hydraulic diameter is fixed is found to be insignificant on the Nussle number, and has no effect on the heat transfer coefficient. And it was found that the effect of hydraulic diameter on friction coefficient and heat transfer is more important when compared with aspect ratio.

Liu et al. [11] in the study of different channel lengths of rectangular microchannels with a hydraulic diameter of 436 μm and a height-to-width ratio of 0.375 found that the channel length has a small effect on the flow resistance; the microchannel length does not have much effect on the Nussle number when the Reynolds number is less than 200, and when the Reynolds number ranges from 200 to 1800, the Nussle number at the same Reynolds number decreases with the increase of the channel length.

Increasing the Reynolds number is an effective method to improve the heat dissipation performance of microchannels. When the hydraulic diameter is constant, the larger the Reynolds number is, the faster the flow rate in the channel is, which can improve the heat transfer rate more effectively. After the above analysis, it can be seen that the hydraulic diameter has a significant effect on the heat dissipation performance of microchannels, and increasing the Reynolds number can enhance the effect of hydraulic diameter on the heat transfer performance.Wang et al. [13] showed that increasing the Reynolds number can improve the effect of hydraulic diameter on the heat transfer rate. As the Reynolds number increases, reducing the hydraulic diameter of the heat transfer rate enhancement is more obvious. However, as the Reynolds number increases, the shear stress on the wall surface inside the channel increases. This results in greater friction and causes higher pressure drop as the fluid flows through the channel [19].

In summary, the heat dissipation performance of the microchannel is affected differently by the geometrical parameters such as cross-sectional aspect ratio, hydraulic diameter, and length of the microchannel; increasing the aspect ratio improves the heat transfer characteristics of the microchannel, but the disadvantage is that the flow resistance inside the channel also increases; decreasing the hydraulic diameter improves the heat transfer characteristics of the microchannel, but the disadvantage is that it increases the coefficient of resistance of the fluid; and the effect of the length of the channel on Nussel number is affected by the change of the Reynolds number and the change.

2.2. Influence of microchannel cross-section shape

To explore more channels with good hydraulic performance and thermal performance, researchers proposed triangular, trapezoidal, hexagonal, rhombic, elliptical, semicircular, and circular channels. Wang et al. [13] compared the thermal performance of rectangular, triangular, and trapezoidal cross-section channels with channel cross-sectional area of 0.1647 mm2 . When the porosity, number of channels, cross-sectional area and hydraulic diameter are the same, the rectangular microchannels have the lowest thermal resistance, followed by trapezoidal microchannels and triangular microchannels; the rectangular microchannels have the largest pressure drop, and the triangular microchannels have the smallest pressure drop. Kose et al. [20] carried out an in-depth study on the above mentioned single-phase fluids for the three different cross-section channels with a hydrodynamic diameter of 150 μm for the microchannels, and found that the thermal performance of rectangular microchannels was better than triangular microchannels when the top angle of triangular channel is 50 ° and the bottom angle of the trapezoidal channel is 60 °, the two channels have the best overall performance. At the same hydraulic diameter, the rectangular channel has the best thermal and hydraulic performance; moreover, at the same heat exchange capacity, the required pump power of the rectangular channel is 17% and 40% less than that of the trapezoidal channel and the triangular channel, respectively. Tran et al. [21] investigated the performance of five different microchannel cross-sectional shapes, namely circular, square, quadrilateral, two concave surfaces, and two convex surfaces, for channel lengths ranging from 0.2 to 5.6 mm and hydraulic diameters of 200 μm. The performance of different microchannel cross-sectional shapes was compared, and the results showed that the circular cross-section had the best thermal performance, with a heat dissipation capacity of up to 1500 W/cm2. In addition, with the increase of the channel length, the maximum wall temperature and the temperature difference increased, resulting in a significant decrease in its heat dissipation capacity. And a detailed numerical study of trapezoidal microchannel radiator with hydraulic diameter of 157.7~248.2 μm was carried out to investigate and define the locally optimal multi-nozzle trapezoidal microchannel radiator with 100~1450W/cm2 heat flow at coolant inlet temperatures ranging from 15~75 ℃ [22]. Gagan et al [23] investigated the flow and heat transfer characteristics of fluids in trapezoidal microchannels under different boundary conditions and developed a three-dimensional numerical model of trapezoidal geometry with side angles of 30 ° and 60 ° and aspect ratios ranging from 0.1 to 10, and the results showed that Nussle number increases with the side angles and aspect ratios of the trapezoidal channel. Moradikazerouni et al. [24] investigated the flow and heat transfer characteristics of a trapezoidal microchannel for five different types of channels with the number of channels being 12, namely, circular, hexagonal, rectangular, straight channel, and triangular, with the number of channels being 12. The effects of Reynolds number and gas inlet temperature on Nussle number, convective heat transfer coefficient and pressure drop for the cross-sectional shapes were found to have the best thermal performance for the triangular and rectangular channels, and the hexagonal shape has the worst heat dissipation performance. From the processing point of view, a straight channel shape is more suitable for practical applications. Alfaryja et al. [25] compared the thermal performance and flow properties of rhombic, circular and hexagonal channels at a heat flow density of 500 kW/m2 , and all other things being equal, it was found that the hexagonal channel had the best heat transfer coefficient and pressure drop, while the rhombic channel exhibited lower wall temperature and thermal resistance. After considering all the factors, the rhombic channel was the optimum choice. Jing et al. [26] compared the performance of elliptical, rectangular and triangular channels. Under the same hydraulic diameter, the triangular channel has the lowest flow resistance and the smallest convective heat transfer coefficient. In contrast, a critical hydraulic diameter exists for rectangular and elliptical sections to differentiate the performance of the two, and rectangular microchannels have larger hydraulic resistance and convective heat transfer coefficients for hydraulic diameters smaller than the critical value, while elliptical microchannels have larger hydraulic resistance and convective heat transfer coefficients for hydraulic diameters larger than the critical value. Lu et al. [27] studied rectangular, semicircular and triangular cross-sectional shaped microchannels and set the equivalent diameter range from 210 to 1069 μm, and the frictional resistance coefficient of rectangular channel was the largest when the equivalent diameters were similar and significantly higher than that of triangular and semicircular channels. Leong et al. [28] investigated the three kinds of cross-sectional channels, circular, square and equilateral triangle, and found that the total entropy production of the circular channel was the is the lowest and in comparison circular cross-section channel is better.

In summary, changes in the geometric structure or cross-sectional shape of the channel affect its characteristic length, which in turn affects the heat transfer and flow properties. Heat dissipation is significantly improved when the channel hydraulic diameter is smaller and the Reynolds number is larger, but this also leads to larger inlet and outlet pressure drops. In practical applications, rectangular channels are easy to obtain and have significant advantages in heat dissipation, but they need to be explored in depth to improve their flow properties to reduce the pressure drop. The performance of channels with different cross-sectional shapes has been evaluated differently by different scholars, and an optimal channel size needs to be found to balance the heat transfer efficiency and pressure drop.

3. Influence of variable cross-section channel on heat transfer in microchannels

In the above methods of enhanced heat transfer, microchannels with uniform cross-section are mainly used, i.e., the cross-section of the channel is kept constant along the direction of fluid flow. However, the drawbacks of uniform cross-section channels are large pressure drop between the inlet and outlet, large temperature gradient along the flow direction, etc. In order to further improve the heat transfer capacity of the microchannel, researchers have proposed the use of variable cross-section structure, which is aimed at destroying the fully developed boundary layer to form a secondary flow, increasing the heat transfer area and thus improving the heat transfer capacity. For example, a rectangular cross-section channel is formed when the width of the channel varies in the form of divergent or convergent asymptotic cross-section channel [29], or a periodic variable cross-section channel is formed by excavating equally spaced and shaped recesses or internal ribs on the channel wall [30].

For convergent channel structures, the main reason for heat transfer enhancement is the acceleration of fluid velocity during the flow. Whereas, the divergent channel increases the heat transfer efficiency due to the increase in heat transfer area. The heat transfer performance of both convergent and divergent channels is better than that of the flat structure. Duryodhan et al. [31] studied single phase liquid flow with trapezoidal cross-section and found that the convergent channel with thinner boundary layer on the side wall has higher convective heat transfer coefficient when all other conditions are the same, and the amount of heat transfer in the convergent channel is about 35% higher than that of the divergent channel.Song et al. [32] took the ratio of widths of both ends of the channel as a study variable, compared the structure of trapezoidal microchannels with different arrangement forms. It was shown that the thermal performance can be effectively improved when the fluid flows from the large end to the small end, and the pressure drop increases with the decrease of the width ratio at the ends, and the pressure drop increases with the increase of the channel height; the increase of the channel height at constant channel volume decreases the hydraulic diameter, which increases the fluid velocity at constant inlet flow rate, thus decreasing the thermal resistance and leading to a more homogeneous temperature distribution. Rajalingam et al. [33] combined convergent and divergent channels to form a convergent and then divergent channel structure and found that the location of the channel "throat" affects the heat transfer performance of the channel. In order to study the influencing factors of the heat transfer capacity of the divergent and convergent channels, Goli et al. [34] designed diamond and hourglass shaped channel structures, as shown in Figure 2. By analyzing the irreversible entropy production, it was found that the friction- and heat-induced entropy production increases with the width ratio at high Reynolds number. In addition, the rhombic channel has better overall performance compared to the hourglass-shaped channel.

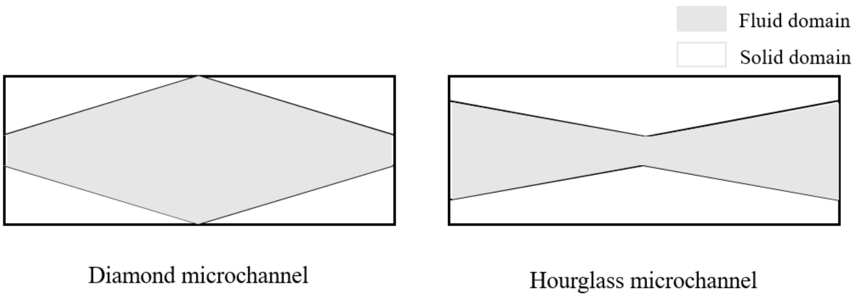


Figure 2: Diamond and hourglass microchannels.

For the periodic variable cross-section channel with concave cavities, researchers generally believe that the vortex is responsible for the enhancement of heat transfer [35-37], and also can effectively reduce the flow resistance [38]. Huang et al. [39] investigated the differences in heat transfer performance and flow performance between two types of variable cross-section channels, semi-circular concave cavities and semi-circular internal ribs, as shown in Fig. 3. Considering a number of performance indicators such as flow resistance, heat transfer capacity and pump power consumption, the results show that the microchannel with dimples has better performance. In order to investigate the effect of different shapes and sizes of dimples or internal rib structures on the channel performance, researchers have conducted more in-depth studies. Kumar [40] studied rectangular microchannels and trapezoidal microchannels and found that the heat transfer capacity of trapezoidal microchannels increased by 12% compared to rectangular microchannels when the same shape of rectangular dimples or semicircular dimples were cut. In addition, different shapes of dimples also affect the heat dissipation capacity. The heat transfer in trapezoidal microchannels with semicircular dimples was 16% higher than that with rectangular dimples. Zhu et al. [41] investigated the effect of five different shapes of dimples, namely, periodic rectangular, triangular, semicircular, water-droplet, and trapezoidal on the performance of the microchannels, and the structure of the microchannels with different shapes of dimples is shown in Fig. 4. The results show that the heat transfer enhancement efficiency of the triangular-shaped dimples is more sensitive to the change of Reynolds number, but the pressure drop increases significantly, while the teardrop-shaped dimple microchannels have the greatest potential to further improve the heat transfer efficiency. However, a comprehensive analysis of the fluid flow and heat transfer reveals that the heat transfer enhancement effect is greater than the pressure drop penalty effect, i.e., the heat transfer gain compensates for the pressure drop loss. Therefore, the triangular shaped recess has the best overall performance. Subsequently, trapezoidal dimples were studied in depth, and by studying the bottom angle of a right-angle trapezoid, it was found that the mixed flow phenomenon was most obvious in the gradually expanding and suddenly contracting dimples, and their heat transfer efficiency was significantly higher than that of the opposite structure [42]. In order to investigate the effect of microchannel structure change on entropy yield and heat transfer coefficient, Zhai et al. [43] studied the channel structure with a combination of triangular inner ribs and triangular dimples. The results showed that with the increase of Reynolds number and the pressure drop, the thermal resistance of this structure was reduced more significantly and the wall temperature distribution was more uniform.

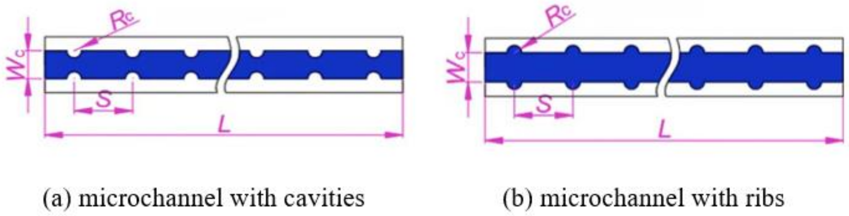


Figure 3: Geometric specification of microchannel.

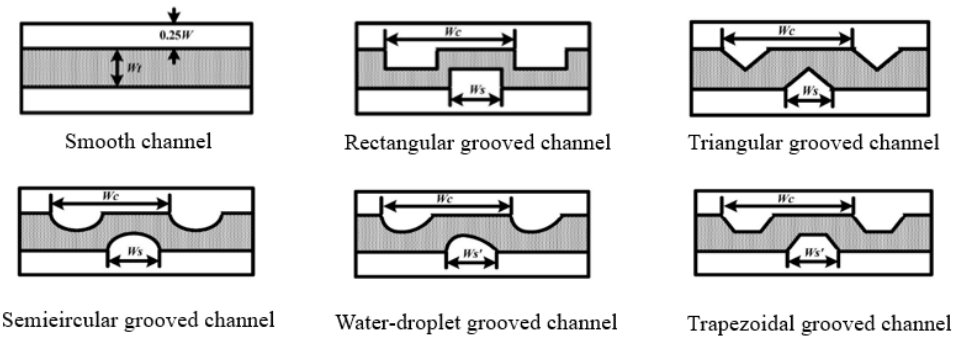


Figure 4: Microchannel cross sections with different shaped dimples.

The above studies mainly focus on enhancing heat transfer by varying the cross-sectional dimensions of the channel. Compared with the uniform cross-section channel, the variable cross-section channel performs better in both heat transfer and flow. The disruption of the boundary layer of the fluid flow by adding periodic pockets can promote fluid flow and heat transfer, and among the different shapes of pockets mentioned above, the triangular pockets have the best overall performance.

4. Bionics-based topology design

In a DC channel structure, the fluid temperature rises rapidly along the flow direction and the outlet temperature is much higher than the inlet temperature, resulting in a significant temperature gradient on the microchannel cold plate. However, good temperature uniformity is an important criterion for the thermal design of electronic chips, which cannot be achieved from optimizing the microchannel size or cross-sectional shape alone. An effective method to improve the microchannel temperature uniformity is to rationally arrange the channel structure in order to change the flow mode, such as increasing fins in the channel to increase the effective heat transfer area, reducing the sharp corners of the flow channel to have less obstruction, and utilizing a fractal structure that can achieve a uniform distribution of velocities, etc. [44]. Applying these methods to the microchannel topology design can improve its heat dissipation performance and temperature homogenization performance.

There are many excellent heat and mass transfer structures in nature, for example, the trunk structure of plants possesses excellent water transport capacity [45,46], leaf veins have excellent mobility performance, and some structures of non-transport systems can also provide references for the design of microchannel topology, such as spider net and snowflake morphology [47], and bionic structures and bionic microchannel structures are shown in Fig. 5. In addition, the epidermal or body morphology of aquatic animals has the property of reducing flow resistance [48,49], and these structures provide ideas for researchers to design microchannel flow channel topologies.

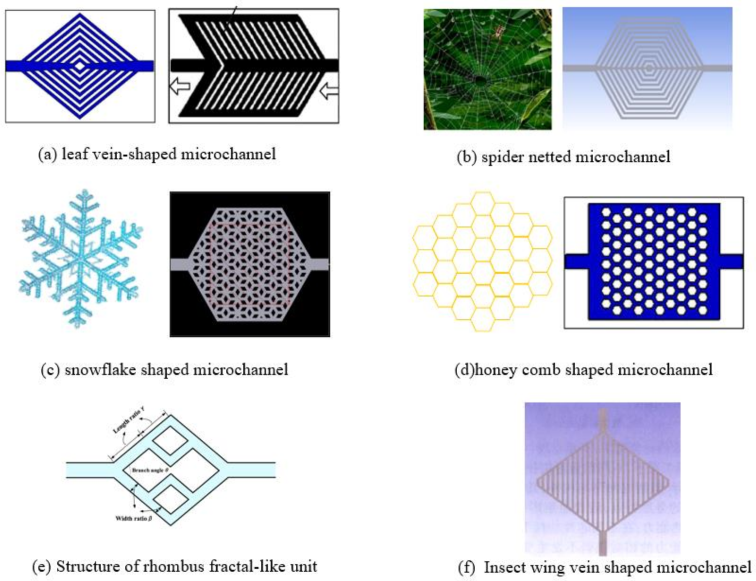


Figure 5: Bionic structure and bionic microchannel structure.

According to the water transport system of tree trunks in nature, Xu et al. [45] investigated the leaf vein-shaped microchannel, and used deionized water as the coolant to explore the effect of the number of stages on the flow performance and heat transfer performance, and determined that the optimal number of stages of the channel was 7, and only lower pumping power was required, whereas too much tree fractal would increase the pressure drop and reduce the heat dissipation effect. It was shown that the heat dissipation effect of the tree microchannel was better than that of the traditional parallel microchannel, and the temperature rise of the tree microchannel was gentle and the temperature difference was smaller, with a temperature difference of only 2.7 ℃, which is lower than that of the parallel microchannel by 17 ℃. In contrast, Tan et al [46,47] used a microchannel with a leaf-vein-type fractal structure to solve the problem of heat dissipation from multiple heat sources, and the maximum temperature difference between the heat sources was reduced from 3.43 ℃ to 2.76 ℃ compared with the flat structure; the numerical simulation results showed that the leaf-vein-type microchannel not only strengthened the heat transfer but also led to a more uniform heat source temperature and a smaller pressure drop than that of the traditional parallel microchannels. In the fractal topology, the fractal angle and the number of gradations are important parameters for enhancing heat transfer and reducing flow resistance. In the above studies, the angle between two neighboring flow stages is 90 °, and the effects of other fractal angles on the microchannel performance are not deeply explored. In this regard, Liu et al. [48] designed four different fractal angles and investigated their effects on the flow rate and velocity in each channel. The results show that, when the Reynolds number is the same and the angle between two adjacent stages is 90 °, the flow rate in the channel is basically constant, but the flow resistance at the fractal is larger, and the pressure drop can be reduced by half when the fractal angle is 45 °. Ji et al. [49] investigated the heat transfer and pressure drop characteristics of the silicon-based fractal tree micro-channel heat sinks with the fractal angles of 30 °, 60 °, and 90 °, and the experimental inlet Reynolds number was 500~1700. The experimental inlet Reynolds numbers were 500~1700, and the tree fractal structures with different fractal angles are shown in Fig. 6. The results show that as the fractal angle decreases, the influence of Reynolds number on the pressure drop decreases, and the overall performance is the best when the fractal angle is 30 °; compared with the traditional microchannel, the pressure drop can be reduced by 92% when the chip temperature is kept below 85 ℃, and the heat transfer coefficient of the fractal microchannel is improved by 1.5 times under the same flow rate; compared with the straight-through channel, the performance of the fractal microchannel radiator with a fractal angle of 30 ° is coefficient was improved by 12-13 times. Xu et al. [50] designed a multilayer fractal flow channel and found that the pressure drop increased with the increase of flow rate, and the maximum temperature was 362 K when the flow rate was 200 ml/min, and 323.5 K when the flow rate was 600 ml/min, which shows that the volume flow rate has a more obvious effect on the temperature. The structure significantly reduces the volumetric thermal resistance of the microchannel heat sink, and the heat transfer performance is more excellent than that of the single-layer structure, and it is found that the heat transfer performance of the heat sink is directly proportional to the number of layers of the microchannel. In addition to the tree structure, other fractal structures in nature can also provide references for microchannel topology design. Zhuang et al. [51] were inspired by the branching vascular tree structure to design a rhombic fractal-like microchannel, as shown in Fig. 7(a), and it was found through the optimization of its geometrical parameters that the pump power was lowest when the fractal angle was 80 °. This structure can improve the performance factor of microchannel heat sink by 7.9% to 68.7% compared with the traditional straight-through channel. Wu et al. [52] compared seven flow channel structures, rectangular flat, river network, insect wing vein, leaf vein type, honeycomb type, lung trachea, and spiderweb, to dissipate heat from a chip with different power under the same conditions. The highest temperature of the chip under the spider web-like structure is the lowest, when the chip heating power is 5W, the highest temperature of the chip under the spider web-like structure is only 1℃ lower than that of the ordinary rectangular flat microchannel, and the difference of the highest temperature is more obvious to be 8℃ as the power is increased to 40W, and the pressure drop of the spider web-like structure is smaller. The spiderweb-like structure has a large heat dissipation area, high average convective heat transfer coefficient, good fluid flow performance, and optimal comprehensive heat dissipation performance, which is nearly 10% higher than that of the rectangular flat microchannel, and it can show even better heat dissipation performance under high heat flow density. Tan et al. [53] investigated the heat dissipation performance of the six structures, namely, the rectangular flat structure, the forked leaf-vein structure, the flat leaf-vein structure, the imitation snowflake structure, the imitation spiderweb structure, and the honeycomb structure, and found that they have a very good performance in heat dissipation of the chip. The heat dissipation performance of the chip was investigated with a heat flux of 100W/cm2 on the chip surface, cooling water as the medium, inlet temperature of 25 ℃, and a volume flow rate of 0.4L/min, and the results showed that the imitation spiderweb structure had the best heat transfer performance, with a maximum chip temperature of 75.5 ℃ but a pressure drop of 22.4kPa, which is twice as much as that of the rectangular flat structure. The number of stages of the imitation spider web structure was also studied in depth, and it was concluded that the heat transfer capacity was best when the number of stages was 9.

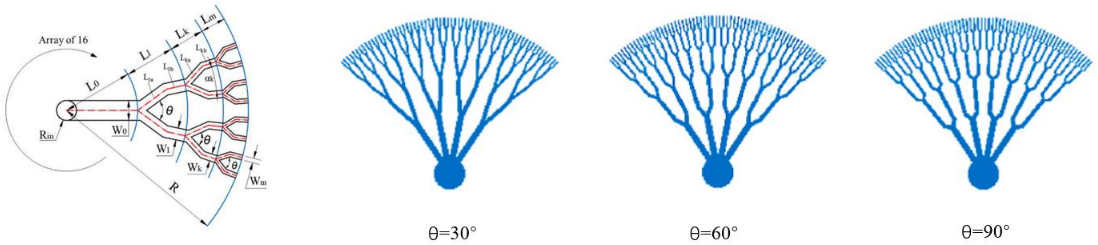
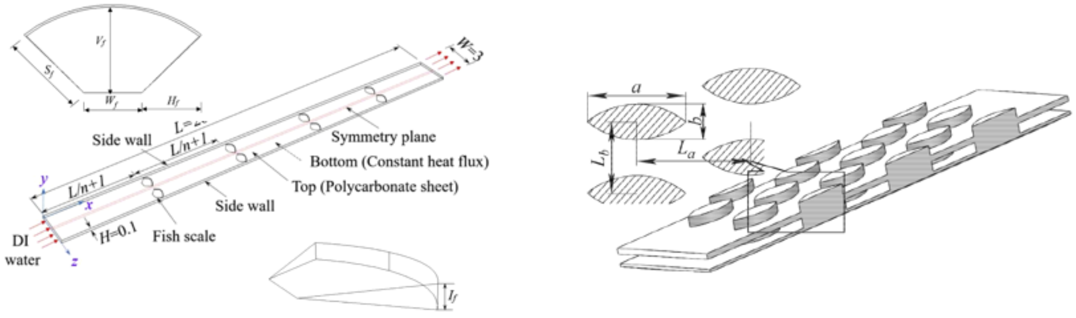


Figure 6: Tree fractal structure with different fractal angles.

Huang et al. [54] applied a periodic variable cross-section structure to a tree-shaped microchannel structure. The effects of two types of variable cross-section channels, concave cavities and inner ribs, on the fractal structure at a Reynolds number of 498 were investigated, and it was found that the variable cross-section structure could further enhance the heat transfer capability of the fractal flow channel, with the center of the channel having a lower temperature in the main flow channel and the temperature near the sidewalls having a higher temperature; and the temperature of the inner sidewalls was lower than that of the outer side after entering the branched flow channel. The inclusion of periodic fin structures in the channel can also effectively improve the flow performance of the channel. In the region with fins, the fluid velocity gradient changes, and at the back end of the fins, the fluid velocity is very small, so a vortex can be formed at the back end of each fin, thus improving the heat transfer rate. In addition, the inclusion of fins in the channel can also increase the heat transfer area and thus improve the heat transfer performance, but different morphologies of fins have different effects on the improvement of heat transfer. Dey et al. [55] designed a fish scale shaped microchannel inside the microchannel, as shown in Fig. 7(a), and explored the effect of the inclination height on the heat transfer performance and flow properties. Compared with the smooth channel, the Nussell number can be increased by 14% at a fin tilt height of 5 μm, and the heat transfer rate increased by 9% when the number of fins was increased from 8 to 10. Gong et al. [56] investigated a heat exchanger with a swordfish shaped microchannel as shown in Fig. 7(b), and analyzed the effect of fins in different arrangements on the heat transfer performance. It was found that at high Reynolds number, decreasing the fin spacing along the flow direction reduces the pressure drop and thermal resistance, and the Nussle number decreases; whereas, in the direction perpendicular to the flow path, increasing the fin spacing improves the Nussle number and enhances the heat transfer performance.



(a) fish scales shaped microchannel (b) Swordfish shaped microchannel

Figure 7: Finned structural channel model.

From the above study, it can be seen that the topology of the bionic microchannels has a significant effect on their heat transfer characteristics, and the performance of the bionic spiderweb structure is better at high heat flow density, and the heat transfer capacity of the channels can be further enhanced when the channel cross-section size is changed. The bionic-based topology can improve the heat transfer characteristics of microchannels while reducing the pressure drop. However, the current research on bionic topology is still at the stage of model simplification, and there is no specific and unified study on the influence of structural parameters and other performance, which still needs more researchers to explore in depth.

5. Conclusions

The development and optimization of microchannel heat sinks point the way to future heat dissipation problems in high power, high heat flow density electronic devices. This paper focuses on the method of enhanced heat transfer by single-phase flow in microchannel heat sinks. With the objectives of improving heat dissipation capability, reducing pressure drop and decreasing pump power consumption, it summarizes and elaborates on the three levels of cross-section size and shape, variable cross-section structural design and bionic topology design, and the following conclusions are obtained from the comprehensive analysis:

(1) the change of the geometric parameters of the microchannel can effectively improve its heat transfer performance, the Nussell number is positively correlated with the growth of the aspect ratio, but it can't grow indefinitely, and with the increase of the aspect ratio, the flow resistance in the channel increases; when the Reynolds number is the same, the drag coefficient increases with the increase of the hydraulic diameter, while the Nussell number and the pressure drop decreases with the increase of the hydraulic diameter; the effect of the length of the channel on the Nussell number is affected by the Reynolds number of the channel, but the effect is small.

(2) Changing the channel cross-section by adding dimples or internal ribs can destroy the boundary layer of fluid flow and promote fluid flow and heat transfer, thus improving the heat transfer performance, but the pressure drop loss increases; the comprehensive performance of microchannels with dimples is better than that of those with internal ribs, and it is found that triangular dimples have the best comprehensive performance in the study of dimples of different shapes.

(3) The cross-sectional shape of the channel is also one of the factors affecting its performance. In practical applications, rectangular channels are easy to obtain, and rectangular channels are preferred for comprehensive consideration, and triangular dimples or fin structures can be added to rectangular microchannels to improve their heat transfer performance.

(4) Bionic-based microchannel topology design is a hot area of current research, and the bionic

microchannel structure is designed by borrowing specific structures that appear in nature. In fractal topologies, the fractal angle and the number of gradations are important parameters that affect the heat transfer performance. The spiderweb structure has the most significant fluid mixing and the largest variation of flow velocity in the channel, which has the best comprehensive characteristics among the bionic structures.

(5) In the single-phase flow enhanced heat transfer technology, how to reduce the pressure drop while improving the heat transfer performance is still a difficult point in the enhanced heat transfer of microchannels, and finding a suitable drag reduction technology is also a key issue to be considered in the future. In the next study, the performance changes can be investigated by changing the channel shape and size of the bionic structure, or by adding dimples or fin structures to the bionic structure.

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