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An overview of passive techniques for heat transfer augmentation in microchannel heat sink

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ABSTRACT

Active and passive cooling are the two possible methods for removing heat. An active cooling system is the one that involves the use of energy as opposed to passive cooling that uses no energy. Passive cooling methods are cost effective and more reliable than active cooling due to the absence of moving parts. Microchannel heat sink is one of high-tech devices that have widely considered passive cooling methods especially for electronics cooling. In this paper, the use of passive cooling methods in microchannel heat sink is comprehensively discussed. This paper also present the effects of some important parameters such as the type of channel types, surface roughness, fluid additives, and Reynolds number on the rate of heat transfer in microchannel heat sink. Finally, the conclusions and important summaries were presented according to the data collected.

1. Introduction

Cooling is one of the major concerns in many different industries, e.g. building energy system, electronic devices, chemical vapor deposition instruments, solar energy collector, furnace engineering, and many more. Heat has to be removed to avoid creation of hot spots that will shortens the life span of mechanical devices or even permanent damage of electronic components. Therefore, an effective cooling technique is necessary to dissipate the heat load on the system and maintain the peak performance in all conditions.

Active and passive coolings are the two possible methods for removing heat. An active cooling system is the one that involves the use of energy as opposed to passive cooling that uses no energy. Passive cooling methods are cost effective and more reliable than active cooling due to the absence of moving parts. Microchannel heat sink (MCHS) is one of high-tech devices that have widely considered passive cooling methods especially for electronics cooling. Fig. 1 shows various passive cooling methods that can be introduced in MCHS.

Microchannel heat sink (MCHS) was first introduced by Tuckerman and Pease [1] as a device to dissipate high heat fluxes. Since then, several authors have performed studies on the performance of microchannel heatsink in dissipating high heat flux [2,3]. Due to the tiny size of channels, the flow in MCHS is predominantly within laminar flow regime. Besides, in the conventional straight MCHS, hotter fluid accumulates at the channel wall and cooler fluid along the channel core due to continuous growth of thermal boundary layer. Therefore, we can see that most of the early studies tried to improve the thermal performance of conventional straight rectangular MCHS by manipulating channel aspect ratio, channel length and wall thickness. While some researchers attempted to introduce disruption of boundary layer in MCHS, some others manipulated the cross-section shape of microchannel (e.g. circular, triangular, and trapezoidal) for the performance enhancement.

Literature records show that there have been a number of valuable reviews on passive cooling techniques. However, review on passive methods for cooling of microchannel heat sink is scarce. Therefore, the aim of this paper is to give a further review on the recent passive cooling methods in microchannel heat sink.

2. Various shapes of microchannel heat sink

In a study by Gunasegaran et al. [4], they numerically analyzed the effect of geometrical parameters on the heat sink performance particularly for triangular microchannels. The Reynolds number ranges of 100–1000 was considered. They found that the rectangular shaped microchannel with the smallest hydraulic diameter has the greatest value of heat transfer coefficient. Investigation on the flow characteristics of water through trapezoidal silicon microchannels with a

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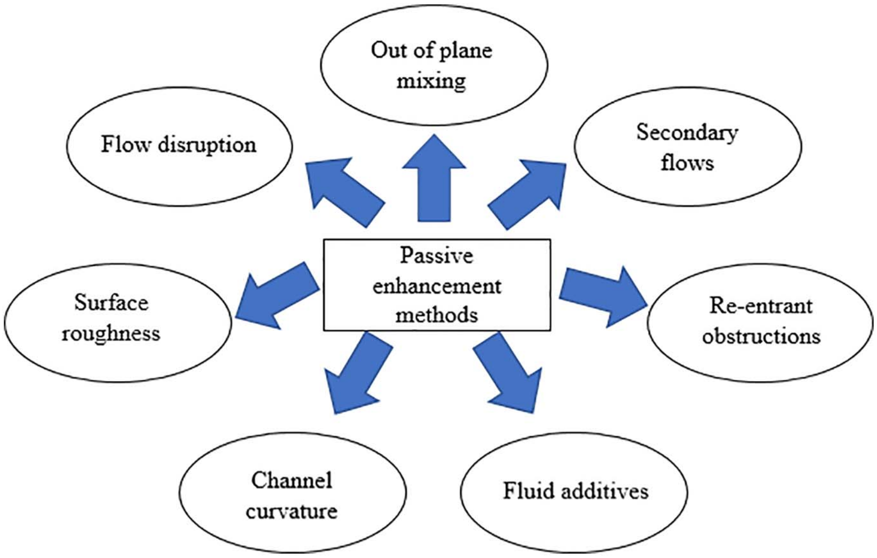

Fig. 1. Passive enhancement methods.

hydraulic diameter ranging from 51 to 169 μm has been conducted by Weilin et al. [5]. They first proposed a new correlation of roughness viscosity for trapezoidal microchannels. Weilin et al. [5] also claimed that this viscosity should be considered in the equation of motion in a manner similar to the eddy viscosity in turbulent flow.

Liu and Garimella [6] performed experimental and numerical investigations on the flow field and pressure drop for water flow in rectangular microchannels. It was found that the conventional correlations offer reliable predictions for the laminar flow. The laminar forced convection flow characteristics through a trapezoidal microchannel have been investigated by Wang and his team [7]. Comparison of wall temperatures and local Nusselt with the numerical study showed good agreement indicated the validity of continuous Navier–Stokes equations at hydraulic diameter 155 μm. Tiselj et al. [8] also confirmed that the heat transfer characteristics may be described by conventional Navier–Stokes and energy equations for Reynolds number ranges 3.2 to 64 and hydraulic diameter 160 μm. This finding is consistent with the earlier study by Wu and Cheng [9]. Wu and Cheng [9] performed numerical and experimental study on laminar flow through smooth trapezoidal silicon microchannel with different cross-sectional aspect ratios and confirmed the validity Navier–Stokes equations even at hydraulic diameter as small as 25.9 μm.

A comprehensive experimental research on trapezoidal microchannel has been conducted by Wu and Cheng [10]. 13 different trapezoidal microchannels were designed and their effects of the geometric parameters, the surface roughness, the surface hydrophilic property on pressure drop and heat transfer in microchannels have been tested. Based on their 168 experimental data points, they proposed new dimensionless correlations for the Nusselt number and the apparent friction factor as below

For $10 < Re < 100$

$$Nu = C_1 Re^{0.946} Pr^{0.488}\left(1-\frac{W_b}{W_t}\right)^{3.547}\left(\frac{W_t}{H}\right)^{3.577}\left(\frac{k}{D_h}\right)^{0.041}\left(\frac{D_h}{L}\right)^{1.369}$$

and for $100 < Re < 1500$

$$Nu = C_1 Re^{0.148} Pr^{0.488}\left(1-\frac{W_b}{W_t}\right)^{0.908}\left(\frac{W_t}{H}\right)^{1.001}\left(\frac{k}{D_h}\right)^{0.033}\left(\frac{D_h}{L}\right)^{0.798}$$

and

$$f_{app}\,Re = C_3 Re^{0.089}\left(1-\frac{W_b}{W_t}\right)^{4.359}\left(\frac{W_t}{H}\right)^{4.444}\left(\frac{k}{D_h}\right)^{0.028}\left(\frac{D_h}{L}\right)^{1.023}$$

In a numerical study by Kim and Kim [11], they extended the previous works [12,13] which was limited to the uniform heat flux boundary condition on the bottom wall of microchannel heatsink. Since the original fin model was found unsuitable for high aspect ratio, Kim and Kim [11] considered a porous-medium approach which was earlier proposed by Koh and Colony [14] to simulate the effects of the aspect ratio and the porosity on the friction factor and the Nusselt number for microchannel heat sinks with a uniform base temperature. Good agreements were obtained when compared to experimental data from literature.

From the above brief literature survey, it can be seen that most of the early researchers have put their effort to improve the thermal performance of conventional straight MCHS by manipulating channel length, channel aspect ratio, wall thickness and even the cross-section shape of microchannel (e.g. circular, triangular, and trapezoidal). However, as mentioned in a report by Ghani et al. [15], the heat transfer enhancement can be further improved by disrupting the development of thermal boundary layer and introduction of secondary flow for better mixing.

Recently, Dewan et al. [16] and Tullius et al. [17] provide a comprehensive review on the techniques for flow disruption in microchannel. In an innovative work by Wang and his co-researchers [18] they proposed tree-shaped branching rectangular microchannel networks to avoid high pressure drop and uneven temperature distribution along the straight microchannel heat sink on a square chip. They found that the proposed design has led to slightly higher pressure drop compared with straight channel, however, it has been demonstrated to reduce the potential of thermal damage due to blockage of fluid flow. This excellent characteristic can be applied to any system that needs high reliability, such as electronic cooling. Summary of various shapes of MCHS is shown in Table 1.

3. Flow disruption in MCHS

The thermal boundary layer development in microchannel heat sink can be disrupted by introducing flow disruption techniques, such as, reentrant cavities, porous medium, ribs and groove structures, dimpled surfaces, etc. These techniques disturb the thickening of boundary layers, enhanced mixing of flow at the leading edge resulting in an increased heat transfer. To fully understand this phenomenon, Hong and Cheng [19] analyzed the fluid flow characteristic and heat transfer in offset strip-fin microchannels heat sinks at different size of strip-fin for electronic cooling purpose. They successfully demonstrated the breakup of boundary layer and enhancement of heat transfer using the proposed design. Mat Tokit and her research members [20,21]