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Parametric study on thermal performance of microchannel heat sinks with internal vertical Y-shaped bifurcations

Gongnan Xie [a,b,*], Han Shen [b], Chi-Chuan Wang [c,*]

[a] Department of Mechanical and Power Engineering, School of Marine Science and Technology, Northwestern Polytechnical University, P.O. Box 24, 710072 Xi'an, Shaanxi, China
[b] School of Mechanical Engineering, Northwestern Polytechnical University, P.O. Box 552, 710072 Xi'an, Shaanxi, China
[c] Department of Mechanical Engineering, National Chiao Tung University, EE474, 1001 University Road, Hsinchu 300, Taiwan

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ABSTRACT

In this paper, internal vertical Y-shaped bifurcation plates are integrated with the microchannel heat sink (MHS), and its corresponding thermal and fluid flow characteristics are investigated numerically. The effect of the length of Y-shaped bifurcation and the angles of the arms on the overall performance are examined. A best Y-shaped plate length are firstly screened out from three designs and are compared with the corresponding rectangular smooth microchannel. Based on the best thermal performance with a specific length, the effect of arm angles in terms of five different configurations of Y-shaped plates are further investigated. Through the calculations, the corresponding flow field, temperature field and pressure drop characteristics are reported. It is found that the thermal performance of MHSs with internal Y-shaped bifurcations is much better than that of the traditional rectangular microchannel. The longest internal Y-shaped bifurcation microchannel results in best thermal performance. On the other hand, a larger arm angle leads to a better thermal performance of the internal Y-shaped bifurcation microchannel.

1. Introduction

For the past few decades, the electronic products continues to shrink its volume and weight. But in the same time, they pack more and more integrated circuits into themselves to achieve complex functions. This inevitably brings out high heat flux for these electronic devices and becomes essentially severe when the space is further reduced. Therefore, the traditional cooling method, e.g. air cooling, becomes insufficient and the requirement for higher performance of cooling methods. Commonly, raising temperature by 10 °C, the reliability of the electronic product will be reduced by half than the original value [1]. The demand for higher performance of the chip and the needs for better cooling methods are becoming imperative as clearly depicted by Prasher and Chang [2].

In order to tailor the issues caused by the high flux chip, Tuckerman and Peasein [3] proposed microchannel heat dissipation technology had been proved effectively and had been implemented successfully. Inspired by the innovative microchannel heat sink design, there had been many subsequent researchers aiming at the improvements and developments. For instance, Rezania et al. [4] used experimentally investigated the feasibility on microchannel heat sink in the thermoelectric applications. Some numerical and analytical analyses upon the performance of microchannel heat sinks were depicted by Shafeie et al. [5], Esmaeilnejad et al. [6], Knight et al. [7] and Mitalare [8].

Lee et al. [9] and Lee and Garimella [10] validated the applicability of classical correlations based on conventional sized channels for predicting the thermal behavior in single-phase flow through rectangular microchannels. Philips [11] provided formulations in designing microchannel geometries by examination of the heat transfer and fluid characteristics in microchannel heat sinks. Kandlikar and Upadhye [12] appreciably extended the heat flux limit by using the microchannel designs and had proposed an optimization procedure for selecting the geometries of the microchannel under the given pressure condition. Also, Xie et al. [13,14] provided a series of numerical studies on the heat transfer and pressure drop characteristics in microchannel heat sinks for chip cooling and concluded that utilization of a thinner thickness of bottom and channel could improve heat transfer performance for both laminar and turbulent flows with acceptable pressure drop penalty.

With the evolvement of optimizing the structure of microchannels, the constructal law is an effective method for it relates the system efficiency and system structure [15]. Bejan [16] firstly presented the constructal law applicable for engineering system in

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* Corresponding authors at: School of Marine Science and Technology, Northwestern Polytechnical University, P.O. Box 24, 710072 Xi'an, Shaanxi, China. Tel.: +86 29 88492611; fax: +86 029 88495278 (G. Xie).

E-mail addresses: xgn@nwpu.edu.cn (G. Xie), ccwang@mail.nctu.edu.tw (C.-C. Wang).

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Nomenclature

A	wall surface area (m^2)
D_h	hydraulic diameter (m)
f	Fanning friction factor
h	heat transfer coefficient (W/m^2 K)
H	microchannel height (m)
n	number of microchannels
p	pressure (Pa)
P	pumping power (W)
q	wall heat flux (W/m^2)
Q	total power generated by the chip (W)
R	overall thermal resistance (K/W)
Re	Reynolds number, $\mathrm{Re} = \rho u_m D_h / \mu$
T	temperature (K)
u	flow velocity (m/s)
V	volumetric flow rate (m^3/s)
W	width (m)

Greek symbols

ΔP	pressure drop (Pa)
α	the angle between the two arms of the bifurcation (°)
λ	thermal conductivity (W/m K)
μ	fluid dynamic viscosity (Pa s)
ρ	fluid density (kg/m^3)

Subscripts

b	bottom surface
c	microchannel
cp	cover plate
f	bifurcation
m	average/overall
s	substrate
w	wall
in	inlet
out	outlet
max	maximum

association with shapes and structures of diverse natural. Ghaedamini et al. [17] and Lorenzini et al. [18] applied the formulations to engineering flow systems. Bejan and Errera [19,20] used the constructal formulations to examine tree-like structured microchannel networks with high conductivity paths. After that, Ghodoossi and Eğrican [21] found out a tree network of high conductive links on the bottom of heat generating area. Besides, Chen and Cheng [22] investigated the flow and heat transfer characteristics about the tree-shaped microchannel heat sinks, showing its outstanding features in terms of both pressure drop and temperature uniformity as compared to traditional serpentine design. Zhang et al. [23,24] performed both experimental and numerical studies on multiple microchannels applicable for electronic cooling. Their design included a straight channel, a serpentine channel and a U-shaped channel with counter flows. Their results showed that the changes of the configuration such as width, depth, and fins will lead to considerably variations in cooling capacity and it was found that heat sink with the U-shaped channel, when compared to the serpentine channels, has a more uniform temperature distribution. Further numerical studies of geometric structure optimization were carried out by Wang et al. [25,26]. In these studies, geometrical optimizations upon channel number N, channel aspect ratio α and width ratio of channel to pitch β were reported.

However, use of microchannel design also incorporated a tremendous pressure drop penalty subject to the same flow rate. To tailor this problem, Vafai and Zhu [27] introduced a new concept of a double-layered microchannel heat sink with counter flow layout. Yet the double-layered microchannel heat sinks showed a substantial reduction in pressure drop and the temperature rise compared to the single-layered microchannel heat sinks. Xie et al. [28] also numerically validated the performance of water-cooled single-layered and double-layered microchannels. Xie et al. [29] performed a comparative study of the flow and thermal performance of double-layered wavy microchannel heat sinks and they also confirmed that the double-layered wavy microchannel heat sinks outperform conventional rectangular straight mircochannels. Lin et al. [30] conducted a numerical analysis upon optimizing the geometry and flow rate distribution for double-layered microchannel heat sinks.

It has been widely recognized that the bifurcation flow might enhance the cooling performance because of the restarting of the boundary of layer. Xie et al. [31] designed a series of microchannels subject to bifurcation, and their numerical results suggested that the microchannel with multistage bifurcation showed a better thermal performance than that of a rectangular microchannel. A numerical study concerning heat removal enhancement with extended surfaces was conducted by Lorenzini and Moretti [32] who showed an obvious augmentation by a decrease of α (the angle between the two arms of the Y bifurcation). Lorenzini and Rocha [33] found that a T–Y assembly of fins to optimize the heat removal, illustrating the Y-shaped bifurcation to be superior to rectangular straight microchannels. Li et al. [34] conducted analysis on the microchannel heat sinks with constructal vertical Y-shaped bifurcation plate pertaining to laminar flow condition. Microchannel heat sink with Y-shaped bifurcation provides larger area of the heat removal surface. This structure shows good thermal performance. Thus Y-shaped bifurcation is a promising choice for improving the cooling performance of the microchannel heat sinks. It suggests that appropriate design of the structure of the microchannel heat sink is helpful for improving the overall thermal performance of the microchannel heat sinks. Lorenzini and Biserni [35,36] conducted some researches concerned with geometrical optimization of Y-shaped cavities intruded into heat generated conducting wall and investigated the effect of the convective heat transfer coefficient in cavity surfaces over the optimal geometry of the cavity, which ideally represents the effect of the Reynolds number over the geometry problem.

Based on the foregoing reviews, the use of internal Y-shaped bifurcation design is proved to be quite effective in microchannel heat sink. However, optimization parameters of this design are not yet fully understood from previous studies. Unlike those structures proposed by Li et al. [34], the structure of this study is that the Y-shaped bifurcation fin is not contacted with the internal walls of the microchannel. Hence this structure may disturb the flow appreciably with complex mixing characteristics. Moreover, the present study aimed at resolving this problem by further optimization of Y-shaped plate lengths and the angles between the two arms of the Y-shaped bifurcation. The relevant thermal performance is then compared with traditional rectangular microchannel design. A total of five typical kinds of Y-shaped bifurcations are numerically examined, namely α = 60°, 90°, 120°, 150° and 180°.