International Journal of Heat and Mass Transfer 117 (2018) 487–497

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

A parametric study on thermal performance of microchannel heat sinks with internally vertical bifurcations in laminar liquid flow

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

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

ARTICLE INFO

Article history:
Received 19 May 2017
Received in revised form 22 August 2017
Accepted 6 October 2017

Keywords:
Microchannel heat sink
Vertical bifurcation
Thermal resistance
Pressure drop
Optimal position

ABSTRACT

The optimal position of internal vertical bifurcation integrated with a microchannel heat sink (MHS) is investigated numerically in the present research. The corresponding rectangular smooth microchannel is compared with those with internal vertical bifurcation. The optimal position along the streamwise direction for interval distances is studied in detail. The corresponding temperature fields, flow fields, pressure drop and thermal characteristics are presented through verified computational model. The numerical simulation indicates that a clear inflection point of pressure gradient may prevail with the presence of internal vertical bifurcation. It is also found that the microchannel heat sink with a small distance between the tail end of internal vertical bifurcation and the outlet of microchannel shows the best thermal performance instead of those with setting the tail end of internal bifurcation at the outlet of microchannel. The proposed optimal design of internal vertical bifurcation shows improved thermal performance without any pressure drop penalty.

1. Introduction

With the advent of high-performance electronics, the problem of increasing heat dissipation may limit further development of ultra-dense circuitry. Yet more sophisticated and enormous packing density comes with shrinkage size of electronic devices as evolution goes further. Consequently, the generated tremendous amount of heat requires exquisite thermal management. Apparently the associated high-density assembly accompanies huge heat flux which may impose an obvious impact on the reliability of the electronic equipment. In general, reliability can be reduced by half for every 10 °C rise of junction temperature of electronics. Moreover, when temperature increases from 75 to 125 °C, reliability is reduced to 20% of the original value [1]. Therefore, it is imperative and a must to tailor the heat dissipation of high-density electronics first before they can reach the consumer market. Hence some typical efficient thermal management of electronics must be made and some typical designs can be depicted in [2–4].

For high flux thermal management, it appears that microchannel heat sinks (MCHS) first suggested by Tucker and Pease [5] in 1981 is among the best candidates to ease the gigantic heat problem. They employed purified water in microchannels, which is fabricated in silicon chips and conducted a series of experiments with microchannel arrays. Their results of MCHS with water showed that the maximum temperature could be controlled within 71 °C subject to the highest flux of 790 W/cm^2. More researchers continued to enhance the MCHS capability for it offers advantages such as surface area to volume, simple structure, small mass and size, high convective heat transfer coefficient. Qu and Mudawer [6] studied the heat transfer characteristics in rectangular MCHS using water as the cooling fluid. In their research, the temperature increased linearly alongside the flow direction. Lee and Garimella [7] studied fluid flow process and heat transfer in MCHS and provided some equations to design microchannels heat sinks in detail. They continued to carry out a series of experimental investigations in rectangular microchannels with the width ranging from 194 to 534 μm [8]. They showed that conventional Navier-Stokes equation is still applicable to predict flow and heat transfer in MCHS. Rezania et al. [9] experimentally investigated the feasibility of MCHS in thermoelectric applications. Peng and Peterson [10] experimentally found that the cross sectional aspect ratio casts significant influence on the pressure drop and heat transfer characteristics of water flowing in smooth rectangular MCHS.

Analytical methods had been made to investigate MCHS. Wang et al. [11,12] conducted analyses to optimize the geometric structures of rectangular MCHS subject to constraint conditions. Shafeie et al. [13], Esmaeilnejad et al. [14] and Mitalare [15] presented

* Corresponding author.
E-mail address: xgn@nwpu.edu.cn (G. Xie).

https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.025
0017-9310/

Nomenclature

A	surface area (m^2)
A_c	cross-sectional area (m^2)
A_b	the area of bottom surface of microchannel heat sinks
A_w	the area of calculated bottom surface of microchannel
D_h	hydraulic diameter (m)
H	height of heat sink (m)
H_c	height of single microchannel (m)
L	length of microchannel (m)
L_{zi}	distance between the tail end of internal vertical bifurcation and outlet of microchannel (m)
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, $Re = \rho u_m D_h/\mu$
T_{ave}	average temperature of channel wall surface
T_{in}	inlet fluid temperature
T_m	average temperature of the coolant
T_{max}	maximum temperature on heated bottom wall
T_{out}	outlet fluid temperature
T_w	thickness of side wall (m)
T_0	thickness of bifurcation plate
u	flow velocity (m/s)
W	width of heat sink (m)
W_c	width of single microchannel (m)
W_b	width of bottom wall with single microchannel (m), $W_c + T_w$
x,y,z	spanwise direction, normal direction, streamwise direction

Greek symbols

Δp	pressure drop (Pa)
λ	thermal conductivity (W/m K)
μ	fluid dynamic viscosity (Pa s)
ρ	fluid density (kg/m^3)

Subscripts

ave	average
b	bottom
c	microchannel
cp	cover plate
in	inlet
max	maximum
w	wall
0	Case 0

some numerical and analytical analyses upon the performance of MCHS. Knight et al. [16] employed empirical correlations to assess the performance of MCHS. Philips [17] reported the fluid flow and heat transfer characteristics in microchannels in association with some microchannel geometries. Wesberg et al. [18] investigated the problem of two-dimensional conjugate heat transfer of MCHS to quantify some detailed temperature distributions alongside the streamwise flow direction. Fedorov and Viskanta [19] studied conjugate heat transfer by developing a three-dimensional model in MCHS. Kandlikar and Upadhye [20] examined optimization procedure for selecting microchannel geometries at a given condition and they also showed that the channel cross section profile plays the most pivotal role on the thermal characteristics.

With the development of computational fluid dynamics (CFD), numerical simulation had been widely used to investigate the performance of MCHS because it offers advantages like lower cost, shorter time to achieve reliable results while still retains good efficiency to solve difficult problems. Xie et al. [21,22] performed a numerical study of laminar and turbulent heat transfer and pressure drop characteristics for water-cooled minichannel heat sinks, revealing that a deep and narrow channel showed better thermal performance than a shallow and wide channel subject to a higher pressure drop penalty. Xie et al. [23] performed numerical predictions for a water-cooled, single-layer wavy MCHS. They concluded that wavy microchannels heat sinks are much superior to straight MCHS having the same cross-section. Lin et al. [24] conducted a numerical analysis concerning the optimization of the geometry and flow rate distribution for a double-layer MCHS. Leng et al. [25–27] optimized the thermal resistance and bottom wall temperature uniformity for double-layered microchannel heat sink with truncated top channels. They found that an appropriate truncated design for the top channel could reduce the top coolant heating effect significantly without the loss of cooling effect.

The bifurcation flow can restart of the boundary layer due to splitting of flow into multiple downstream, yielding higher heat transfer performance accordingly. Leng et al. [28] conducted the research concerning fluid flow and heat transfer in microchannel heat sink based on porous fin design concept. The results showed that the pressure drop of the new design is reduced by 43.0–47.9% at various coolant flow rates as compared with that of the conventional heat sink, without only about 5% increase in the thermal resistance. By designing a series of microchannels with the presence of bifurcation, Xie et al. [29] numerically investigated MCHS with a series of parametric influences of bifurcation. Their results suggested that the microchannel with multistage bifurcation showed a better thermal performance than that of a rectangular microchannel. Lorenzini and Moretti [30] conducted a numerical study concerning heat transfer enhancement with extended surfaces. They showed an evident augmentation by decreasing the angle between the two arms of Y-shaped bifurcation (α). Lorenzini and Rocha [31] designed a T-Y fin to optimize the heat transfer and concluded that the Y-shaped bifurcation in microchannel is superior to straight rectangular microchannel. Lorenzini and Biserni [32,33] conducted some geometrical optimizations of Y-shaped bifurcation cavities intruded into heat generating wall. They investigated the optimal geometry of the cavity, which ideally represents the effect of the Reynolds number over the geometry. Li et al. [34] numerically analyzed MCHS with constructal vertical Y-shaped bifurcation plate pertaining to laminar flow condition. The structure reveals good thermal performance because MCHS with Y-shaped bifurcation provide larger heat removal surface.

Based on the foregoing reviews, there are numerous researches that had been carried out upon the MCHS with bifurcation. However, there were no researchers conducted studies concerning the variation of thermal performance with the variation of bifurcation position. Instead, some researchers directly set bifurcation to the outlet of the MCHS without further consideration for the position influence of internal bifurcation. Hence the objective of this study is to clarify the associated parametric influences of bifurcation positions in MCHS, which differs from the former bifurcation researches in MCHS. And a total of eight designs are investigated