International Journal of Heat and Mass Transfer 91 (2015) 656–670

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Experimental and numerical study of thermal enhancement in reentrant copper microchannels

Daxiang Deng [a,b,*], Wei Wan [a,b], Yong Tang [c], Haoran Shao [c], Yue Huang [d]

[a] Department of Mechanical & Electrical Engineering, Xiamen University, Xiamen 361005, China
[b] ShenZhen Research Institute of Xiamen University, ShenZhen 518057, China
[c] Key Laboratory of Surface Functional Structure Manufacturing of Guangdong High Education Institutes, School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou 510640, China
[d] Department of Aeronautics, Xiamen University, Xiamen 361005, China

ARTICLE INFO

Article history:
Received 9 May 2015
Received in revised form 5 August 2015
Accepted 7 August 2015
Available online 22 August 2015

Keywords:
Microchannel heat sinks
Forced convection
Reentrant
Heat transfer enhancement

ABSTRACT

A unique reentrant microchannel heat sink is developed in this study. It consisted of 14 parallel Ω-shaped reentrant copper microchannels with a hydraulic diameter of 781 μm. Single-phase convective flow and heat transfer performance of reentrant microchannels (REEM) were comprehensively explored both experimentally and numerically, and their cooling effectiveness was compared with conventional rectangular microchannels. Utilizing deionized water as the coolant, tests were conducted at Reynolds number of 150–1100, three different heat fluxes, and two inlet temperature of 33 and 60 °C. The results show that the averaged Nusselt number of reentrant microchannels increased up to 39% and the total thermal resistance decreased up to 22% as compared to the rectangular counterpart. Moreover, the reentrant microchannels also maintained notably lower wall temperatures, while they just incurred slightly larger or comparable pressure drop penalty. The above heat transfer enhancement is associated with the flow separation caused by the throttling effects, the acceleration of fluid in the main flow and the intensification of fluid mixing in the unique reentrant configurations of REEM. This study sheds some lights on the design of advanced microchannel heat sinks and is believed to be of practical importance.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

The miniaturization of microelectronic devices coupled with the increased power dissipation has accentuated the need for highly effective and compact cooling methods. Microchannel heat sinks have attracted particular attentions in both heat transfer and microelectronics community [1] since the pioneer work of Tuckerman and Pease [2], as they combine the merits of very high surface area to volume ratio, large heat transfer coefficient and small coolant inventory. To date, a large amount of researches have been dedicated to access forced convection characteristics of microchannels with conventional shapes, such as circular (microtubes) [3,4], rectangular [5,6], trapezoidal [7,8] or triangular [9] ones. Both experimental and numerical methods have been adopted to comprehensively identify the heat and mass transport characteristics in these microchannels, as reviewed in [10] to name a few.

Recently, alteration of channel geometries or flow passages of microchannel heat sinks has been recognized as an efficient method to promote the forced convective heat transfer, which builds an important direction for the passive heat transfer enhancement at microscale. Based on the constructal theory to minimize the flow resistance between a volume and a point, Bejan and Errera [11] proposed a tree-shaped channel network. Subsequent studies by Pence [12], Chen and Cheng [13] and Yu et al. [14] confirmed the fractal-shaped microchannels enhanced heat transfer rates as compared to conventional ones. Using the boundary layer reinitializing concept, Xu et al. [15,16] developed interrupted silicon microchannel heat sinks with parallel longitudinal microchannels and several transverse microchannels. Both experimental and numerical results demonstrated that the reentrant space created by transverse cuts interrupted the normal development of thermal and hydraulic boundary layer, and local heat transfer enhancement was achieved. Also motivated by the concept of the redevelopment of boundary layer, Lee et al. [17] proposed microchannel heat sinks with oblique fins inside the flow channels. The heat transfer enhancement was experimentally and numerically demonstrated, as the breakage of continuous fin into oblique sections and the secondary flow due

* Corresponding author. Tel./fax: +86 592 2186383.
E-mail address: dxdeng@xmu.edu.cn (D. Deng).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2015.08.025
0017-9310/© 2015 Elsevier Ltd. All rights reserved.

Nomenclature

A_{ch}	total heat transfer area of microchannels, m^2
$A_{c,s}$	cross-sectional area of a single reentrant microchannels, m^2
A_c	total cross-sectional area of microchannels, m^2
D_h	hydraulic diameter, mm
H_{slot}	height of slot, mm
h_{sp}	single-phase heat transfer coefficient, kW/m^2 K
k_{Cu}	thermal conductivity of copper block, W/m K
k_m	thermal conductivity of microchannels, W/m K
k_s	thermal conductivity of solder, W/m K
k_f	liquid thermal conductivity, W/m K
L	length of heat sink, mm
l_{tci}	distance from the inlet to thermocouple location in the stream-wise direction, m
l_{Cu}	distance between the thermocouple and the top surface of copper block, m
l_{hs}	distance between heat sink bottom surface and the bottom of circular portion of reentrant cavity, m
m	fin parameter
$\dot{m}$	mass flow rate, kg/s
N	number of reentrant microchannels
P	wetted perimeter of a microchannel, m
P_{cir}	perimeter of circular portion of reentrant microchannel, m
P_{in}	inlet pressure, kPa
P_{ou}	oultet pressure, kPa
$\triangle P$	pressure drop, kPa
q_{eff}	effective heat power, W
q''_{eff}	effective heat flux based on platform area, kW/m^2
r	Radius of the circular cavity, μm
Re	Reynolds number, dimensionless
R_t	Total thermal resistance, °C/W
T_{tci}	Thermocouple reading (i = 1–5), °C
T_{in}	inlet fluid temperature, °C
T_{out}	outlet fluid temperature, °C
$T_{w,tci}$	channel bottom wall temperature at thermocouple location (i = 1–5), °C
$\bar{T}_w$	average wall temperatures, °C
$\bar{T}_f$	average fluid bulk temperature, °C
u	flow velocity, m/s
$\dot{V}$	volumetric flow rate, L/h
X, Y, Z	Cartesian coordinates, dimensionless
W	Width of heat sink, mm
W_{fin}	width of fin between two reentrant microchannels, mm
W_{slot}	width of slot of reentrant microchannels, mm
W_{rec}	width of rectangular microchannels, mm
Nu	Nusselt number, dimensionless

Greek symbols

η	fin efficiency
ρ	density of fluid, kg/m^3
θ	arc angle of the circular cavity
μ	dynamic viscosity of the fluid, N s/m^2

Subscripts

cir	circular portion
Cu	copper
hs	heat sink
fin	fin
tci	thermocouple location
in	inlet
slot	slot

to the oblique cuts resulted in the re-initialization of thermal boundary layers. Moreover, Foong et al. [18] numerically explored heat transfer and fluid flow characteristics in a square microchannel with four longitudinal internal fins. In addition, swirl microchannels of different rectangular cross-sections employed by Xi et al. [19] were found to introduce secondary flows and meliorate the synergy between the velocity field and the temperature gradient field. Improved heat transfer performance by 50% on average were experimentally accessed, despite that it was at the expense of increasing flow resistance. Three-dimensional wavy microchannels with rectangular cross-section were numerically studied by Sui et al. [20] for laminar water flow and heat transfer. It was found that the generation of secondary flow (dean vortices) in the wavy microchannels induced chaotic advection, which could greatly enhance the convective fluid mixing and result in much better heat transfer performance.

Besides of the above means, the reentrant cavities or dimples have been also found to be another good choices, which were especially emphasized in the review works of Steinke and Kandlikar [21]. The reentrant cavities have been adopted on the sidewall or bottom of microchannels, and their merits in reinitializing the thermal boundary layer have been demonstrated repeatedly [22–27]. Wei et al. [22] devoted numerical efforts to studying a rectangular microchannel with a dimpled bottom surface, and proved the effective passive heat transfer augmentation of dimples in microchannels. Ansari al. [23] demonstrated the improved heat transfer performance when the microchannel heat sink was equipped with a grooved structure compared to a smooth one. Abouali and Baghernezhad [24] numerically accessed the convective heat transfer enhancement via the formation of rectangular and arc reentrant grooves in the sidewall of microchannels. Similarly, Kuppusamy et al. [25] introduced triangular grooves in the sidewall of microchannels. Heat transfer enhancement were reached in their numerically investigations, as the triangular grooves contributed to the redevelopment of thermal and hydraulic boundary layers, vortices generation and the increased heat transfer surface at the groove area. But the pressure drop increased notably. Xia et al. [26,27] numerically reported convective heat transfer enhancement by introducing triangular, offset fan-shaped and aligned fan-shaped reentrant cavities in the flow direction of microchannels, whereas a much larger pressure drop and pumping power is still unavoidable.

From the above literature review, it is clear to see that the addition of reentrant cavities or dimples on the sidewall or bottom of microchannels provides a potential and efficient method for the enhancement in forced convective heat transfer, while the pressure drop plenty may invertible increase. To address these issues, we in the present study introduce a type of reentrant copper microchannels (REEM) with a unique Ω-shaped reentrant cross-section configuration, differing from those rectangular microchannels with reentrant cavities on the sidewall or bottom in the literatures considerably. Both experimental and numerical studies were conducted together with the comparison against conventional rectangular microchannels (RECM). Forced convection performance of water was comprehensively accessed at a wide range of Reynolds numbers. This study sheds some lights on the design of advanced microchannel heat sinks and is believed to be of practical importance.

Download English Version:

https://daneshyari.com/en/article/7056339

Download Persian Version:

https://daneshyari.com/article/7056339

Daneshyari.com