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A REVIEW OF HEAT TRANSFER AND LAMINAR FLOW IN A MICROCHANNEL

Mohit Kumar [1], Rajesh kumar[2]

[1]*Department of Mechanical Engineering, NIT Kurukshetra, India*

[2]*Assistant Professor, Department of Mechanical Engineering, NIT Kurukshetra, India.*

*Author's e-mail: mohit63368@gmail.com, Corresponding author's e-mail: rajeshkr@*nitkkr.ac.in

ABSTRACT

A comprehensive review of heat transfers and laminar flow through microchannels has been presented in this paper. In the past few years due to multifunction and high power demand, the heat flux per unit area has increased significantly. Microchannels, have large heat transfer surface to volume ratio and small volumes, shown a good thermal performance. Microchannels have been proven to be a high performance cooling technique which is able to dissipate heat flux effectively over small surface area. A good amount of heat transfer augmentation techniques has been reported in the interrupted microchannel. Due to the free stream separation at leading edge and mixing of fluid results in increased in heat transfer in microchannels. Flow disruption in the microchannel can be achieved through surface modifications, such as, shape of channel, dimple surfaces, ribs, cavities etc. In this paper, combined effect of these surface modification in heat transfer augmentation are reported. Also, the recent developments in experimental and numerical simulation of liquid cooled microchannel have been discussed to analyze pressure drop, temperature variation and heat transfer characteristics due to different surface modification. It has been observed that interrupted microchannel are more effective for heat transfer. The review concludes with suggestions for future research in this area.

I. INTRODUCTION

Due to the rapid development of very large-scale integration technology(VLSI) and Micro-Electro-Mechanical System(MEMS), the application of the microchannel heat sinks is increasing day by day, due to their advantages such as light weight, compactness and higher heat transfer surface area to fluid volume ratio compared with another macroscale system. These microchannel can be applied to the cooling electronic devices, laser process equipment, and aerospace technology. Due to their small hydraulic diameters, heat transfer coefficient is very high although there is high-pressure drop per unit length. The high pressure gradients have led to low flow rates that reduce the ability of the fluid stream to carry heat away for a given temperature rise. There are several methods to increase heat transfer but among these methods, to interrupt the thermal boundary layer, to enhance mixing of the cold and hot fluid, and to induce the mainstream separation are significant means to enhance heat transfer in microscale.

Microchannel cooling was first time demonstrated by Tuckerman and Pease [1]. They achieved high heat flux removal capacity of up to 800 W/cm2. They noted that as the hydraulic diameter of the channel decreases, the heat transfer coefficient increases. So, higher value of heat transfer coefficient comes at the cost of higher pressure drop and hence required greater pumping power. Both liquid and gaseous coolants are used for cooling purpose and each has its advantages and disadvantages. Water and air are the most commonly used fluids in microchannel. In microchannels, air has been used to cool electronic components. However, when heat fluxes exceed 10^6 W/mm2, air cooling methods have become inadequate for most applications as compared to the liquid cooling. In this paper we have reviewed different studies dealing with heat transfer and laminar flow analysis for interrupted microchannels

II. MODEL FORMULATION AND SOLUTION METHODOLOGY

In order to understand the liquid flow and heat transfer in micro channels of the present study, following assumptions are employed: -

(1) Developing flow in micro channels

(2) Steady, laminar flow and heat transfer

(3) Axial thermal conductivity

(4) Viscous dissipation

(5) Varying fluid thermal-physical properties.

Based of above assumptions, governing equations can be written as follow:

- **Continuity equation**

$$\nabla \quad = 0 \qquad (1)$$

- **Navier-Stokes Momentum equation**

$$= - \nabla p + \quad \nabla^2 \qquad (2)$$

- **Energy Equation**

$$= \quad \nabla^2 \qquad (3)$$

The governing equations are solved using the computational fluid dynamics solver ANSYS FLUENT. The SIMPLEC/SIMPLE algorithm is used to solve these governing equation for velocity, pressure and temperature in the control volume. The standard discretization scheme is used in the modelling following the second order upwind scheme for momentum and energy discretization

III. REVIEW OF INTERRUPTED MICROCHANNEL HEAT SINK

Lei Chai et al. [1] performed numerically simulation of three dimensional model to study laminar flow and heat transfer in the interrupted microchannel heat sink with ribs in the transverse microchamber. Five different rib configurations were considered including rectangular, backward triangular, forward triangular, diamond and ellipsoidal. They found heat transfer enhancement mainly due to the mixing of cold and hot water in microchamber and redevelopment of the thermal boundary layer in the microchannel regions. Also, it was found that ellipsoidal ribs in the transverse microchamber shows the best heat transfer performance.

Ji Zhang et al. [2] investigate experimentally the heat transfer and flow characteristics of a multiport minichannel flat tube (MMFT) with a kind of axially continuous saw-toothed (two-dimensional) fin structure. They MMFTs with fourteen types micro-fin structures as test sections and water as working fluid. The aim was to study the effects of fin structure elements on heat transfer and pressure drop, including the height of fin (H_f), the bottom width of fin (W_f), the distance between two neighbouring fins (S_1) and the number of fins in a channel (N). The results show that Fin structure can enhance heat transfer with penalty of increased pressure drop and the Nusselt number increases by up to 138%. Fin structure also lead to the slightly earlier laminar–turbulent transition with Re_{cr} = 1500–1800. It was also observed that for heat transfer enhancement, the increment of heat transfer area has significant effect in the laminar region. And the disturbance caused by elements of fin structure has more significant effect in the turbulent region.

Lei Chai et al. [3] studied a three-dimensional numerical model of the interrupted microchannel heat sink to study

the effects of pressure drop and heat transfer characteristics due to various dimensions and positions of rectangular ribs in the transverse microchamber. In addition, the fluid flow and heat transfer mechanisms of the newly proposed microchannel heat sink are analysed. The results show that There are three most notable effects of the new interrupted

microchannel with rectangular ribs in the transverse microchamber on the mainstream flow, including mainstream flow separation, recirculation or vortex, interrupted boundary layer. For heat transfer enhancement, the interrupted microchannel with ribs is suitable to the operating condition of Re < 600, and for Re > 600, the interrupted microchannel without ribs is considered better. With a fixed rib width value, there is an optimum operation scope for the new interrupted microchannel. The new interrupted microchannel with L=0.5 mm provides the highest enhancement factor while the one with L=0.1 mm yields the lowest.

J.L. Xu et al. [4] demonstrated a new silicon microchannel heat sink, composing of parallel longitudinal microchannel and several transverse microchannel, which separate the whole flow length into several independent zones, in which the thermal boundary layer is in developing. The redeveloping flow is repeated for all of the independent zones thus the overall heat transfer is greatly enhanced. The result shows that for the conventional triangular microchannel heat sinks, the chip temperature versus the flow direction is not linear, behaving the ''horseback'' shape. The ''thermal entrance length'' can be longer than half of the total heating length. The maximum chip temperature occurs just upstream of the ended heating length. Apparent temperature gradients occur at the margins of the focused heating area, due to the thermal conduction in the solid silicon. The heat sink with transverse microchannel also has the non-linear distributions of temperatures and Nusselt numbers. Parameter gradients appear at the margins of the selected heating area. Besides, the parameters show the cycle behaviour. In each independent zone, the Nusselt number is lower in the transverse microchannel region, but will have a sharp increase followed by a slow decrease. The heat transfer is indeed enhanced due to the thermal boundary layer redeveloping mechanism.

Jinliang Xu et al.[5] provide three-dimensional numerical simulations of conjugate heat transfer in conventional and the newly proposed interrupted microchannel heat sinks. The new microchannel heat sink consists of a set of separated zones adjoining shortened parallel microchannel and transverse microchamber. Multi-channel effect, physical property variations, and axial thermal conduction are considered. The result show that The hydraulic and thermal boundary layers are redeveloping in each separated zone for the interrupted microchannel heat sink, with the slower development of thermal boundary layer than that of hydraulic boundary layer. The repeated thermal developing flow enhances the overall heat transfer in such a heat sink. There are two effects influencing pressure drops across the newly proposed silicon chips. The first one is the pressure recovery effect when liquids leaves the upstream zone and mixes in the microchamber, while the second one is the increased head loss once liquid enters the next zone. The first effect compensates or suppresses the second one, leading to the similar or reduced pressure drop for the interrupted microchannel heat sink than that for the conventional one.

Guodong Xia et al. [6] investigated on fluid flow and heat transfer characteristics in a microchannel heat sink with offset fan-shaped re-entrant cavities in sidewall. The computational fluid dynamics is used to simulate the flow and heat transfer in the heat sinks. The steady, laminar flow and heat transfer equations are solved in a finite-volume method. The SIMPLEX method is used for the computations. The effects of flow rate and heat flux on pressure drop and heat transfer are presented. The result indicates that for smaller Reynolds numbers, the friction factor of the OFRM is significantly lower and then larger gradually than the CRM as the Reynolds number increased. The curves of the friction factor versus Reynolds number coincide with each other for the OFRM and clearly separated from each other for the CRM with different heat flux on the bottom of the microchannel.

Liang Wang et al. [7] investigate The heat transfer enhancement of microchannel heat sinks with periodic expansion–constriction cross- sections. Each heat sink consists of 10 parallel microchannel with 0.1 mm wide and 0.2 mm deep inconstant cross-section segment and each microchannel consists of an array of periodic expansion–constriction cross-sections. Three-dimensional laminar numerical simulations are obtained for pressure drop and heat transfer in these microchannel heat sinks under the same experimental conditions. The results show that Compared with the rectangular heat sink, the pressure drop of heat sink with periodic expansion–constriction cross-sections is lower as $Re < 300$, but increases rapidly and is obviously higher as $300 < Re < 750$. And, compared with the heat sink R, heat transfer is enhanced remarkably for the newly proposed heat sinks with periodic expansion–constriction cross-sections, and the averaged Nusselt number could be increased by about 1.8 times.

Mingzheng Zhou et al. [8] provide three-dimensional numerical simulations of conjugate heat transfer in the newly proposed microchannel with different structural parameters. The structural parameters include the lengths and widths of the constant cross-section region and the arcuate region. The effects of structural parameters on pressure drop and thermal resistance was presented. The results show that The mechanisms of fluid flow and heat transfer for the microchannel with aligned fan-shaped re-entrant cavities mainly attribute to the redeveloping boundary layers, the jet and throttling effects, the slipping over the re-entrant cavities and the increased heat transfer surface area provided by the fan-shaped re-entrant cavities. The redeveloping boundary layers, the jet and throttling effects and the increased heat transfer surface area enhance heat transfer, but augment pressure drop. The slipping over the re-entrant cavities reduces the friction factor, but seriously impedes heat transfer mainly attributing to the significantly lower viscosity and conduction level.

Haiyan Wang et al. [9] numerically investigate The effect of geometric parameters on water flow and heat transfer characteristics in microchannel heat sink with triangular re-entrant cavities. A three-dimensional laminar flow model with the conjugate heat transfer between the silicon base and water taken into consideration is solved numerically. In order to find the optimum geometric parameters, four variables, representing the distance and geometry of the triangular re-entrant cavity, are designed. The heat transfer enhancement mechanism of the microchannel with triangular re-entrant cavities can be attributed to not only the vortices formed inside by the re-entrant cavity leading to chaotic advection and convective fluid mixing but also the interrupted and redeveloped periodically thermal boundary layer along the constant cross-section surface.

Y.J. Cheng et al. [10] focused on the investigation of numerical simulation of stacked two-layer microchannel heat sink with enhanced mixing passive microstructure. the microchannel with embedded passive microstructure is chosen. The computational fluid dynamics (CFD) will be used to simulate the flow and heat transfer in a stacked two-layer microchannel with multiple MEMS easy-processing passive microstructures. They found that The thermal resistance of stacked two-layered microchannel heat sink with multiple passive microstructure is compared with previous single smooth and two-layer smooth microchannel. The enhanced mixing mechanism of cold and hot fluid can lead to better heat transfer and lower thermal resistance. The increase of the ratio of the height of passive microstructure to microchannel height (h/Hch1) leads to lower thermal resistance.

IV. CONCLUSION

There is an ever growing need to raise the heat-flux removal levels for thermal management of electronic devices or chips. This review also provides an overview of the recent developments in heat transfer augmentation techniques through various flow disruption methods, such as, shape of channel, dimple surfaces, ribs, cavities, groove structures, etc. Combined effects of these geometrical configurations in heat transfer augmentation are also reviewed. These promote free-stream separation at leading edge which result in boundary-layer development and enhanced mixing leading to increase of heat transfer. Different results show that the flow disruption techniques can provide effective heat transfer enhancement with lower penalties of increased pressure drop. An optimization of geometrical configuration of flow disruption techniques is needed to fully explore its potential considering suitable fabrication techniques for mass production. For industrial applications of high heat flux removal technology, reliability and cost are the key factors to be considered in future.

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