Effect of Various Heat Augmentation Techniques on Performance of Microchannel Heat Sink - A Review

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Abstract – *This review paper is comprehensive study of various ways for heat transfer augmentation in micro-channel heat sink e.g. geometric optimization, employing better hydrothermal property coolant, modification of geometry for flow interruption, mixing of fluid and other various design modifications which were implemented and studied numerically and experimentally have been discussed in the paper. By considering these modifications we can increase the performance of microchannel and design an efficient microchannel heat sink.*

Key Words: Microchannel heat sink1, Heat transfer2, Pressure drop3, Numerical4, Optimization5

1.INTRODUCTION

In modern world emerging growth in IT industries and technical advancement have led to miniaturization of electronic device to accomplish emanating requirements of society. It has reduced the weight and volume of electronic devices and space density also has increased. Due to integration of so many components (Transistors, amplifier and resistors) within constrained space like Li-Ion battery in mobile phones, electric vehicle, microprocessor, laser equipment and super computers etc. generate higher heat flux ranges from 100-300 W/cm^2 [1] which degrade the performance, shorten the mean time to failure and reliability of electronic devices.

To conquer above problem conventional techniques are not adequate and thermal management became tedious and stringent task. There are some effective techniques to dissipate more heat from devices are as follows

- Micro jet impingement.
- Micro heat pipes.
- Microchannel Heat Sink (MCHS).

Out off these techniques MCHS is most prominent and effective technique because it has small size, augmented heat transfer, less cooling liquid required, small ratio of load/volume and low operating cost.

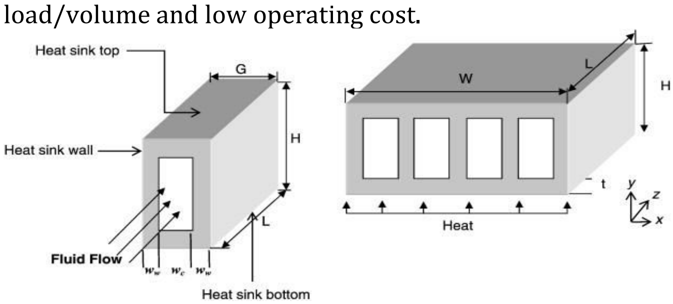

Fig. -Rectangular Straight Microchannel Heat sink model

2. LITERATUE REVIEW

Heat dissipation is limited through straight microchannel heat sink and insufficient to fulfil increasing demand, so there are various ways mentioned in literatures to enhance heat transfer from MCHS. Some of those are as follow: -

1. Optimization of geometry.
2. Use better hydro thermal property fluid
3. Flow interruption and manipulation in geometry for more uniform coolant distribution.

2.1 Geometric optimization is carried out to determine optimal aspect ratio of MCHS that minimized overall maximum temperature, pressure drop and maximized heat transfer. It can be done by Numerical simulation and mathematical optimization to design MCHS, taking more design parameter (channel width, length, channel wall thickness, cross sectional area etc..) into account will result in better cooling capability.

T. Bello Ochende et al. [2] has optimized numerically MCHS and found that the optimal aspect ratio is function of applied pressure drop and solid volume fraction.

2.2 Use of better hydro thermal property fluid

It also enhances heat transfer significantly, higher thermal conductivity and lower viscosity fluid increase heat transfer and decrease pressure drop respectively. Nanofluids have higher thermal conductivities compared to the base liquids and also enhance heat transfer rates [3-4]. Although nanofluids improve the thermal performance of microchannels but it also creates problem of sedimentation of particles, fouling, high pressure drop, erosion and even clogging of channels over prolong use [5]. In MCHS heat flux is not always uniform, slightly increase in heat generation can cause deteriorating effect on heat transfer by nanofluid because surfactant starts to disappear under elevated temperature that causes instability of Nano particle in base fluid these particles adhere on channel wall and form layer on walls that reduce heat transfer [6].

2.3 Flow interruption and manipulation in geometry: -

An alternative way of boosting heat dissipation rate is to disturb the flow and generate turbulence in fluid that will cause uniform temperature distribution and heat transfer. There are many approaches found in literatures which are classified as follows

2.3.1 Modification in channel cross-section area: -

In attempt to improve heat transfer by changing cross section of microchannel several studies are found.

V. Sarath Teja et al. [7] has done a numerical investigation on different MCHS (rectangular, triangular, pentagonal and circular) by parallel and counter flow study it was observed that rectangular microchannel heat sink gives better volumetric heat transfer coefficient 0.64 W/cm^{3}K in counter flow when compared to other cross-sectional microchannel heat sinks.

R. Vinoth et al. [8] an experimental investigation was performed to examine heat transfer and flow characteristics are for three cross-sections of varying mass flux. The trapezoidal channel cross-section increases the significant heat transfer rate improvement for both water and nanofluid by 3.133% and 5.878% compared to square and semicircle cross section. Also, the pressure drop is higher in the trapezoidal cross-section over the square and semicircle cross section due to increase in friction loss of trapezoidal cross section.

2.3.2 Modifying channel shape configuration

Conventional MCHS is a straight rectangular microchannel in which fluid flow nearly along the straight line. When liquid flows through curved passages, there is a generation of secondary flow which improves mixing as well as heat transfer. Performances of microchannel heat sink with different types of channel shapes have been studied widely by many researchers.

Rosaguti et al. [9, 10] examined effect of channel shape on heat transfer characteristics using periodic serpentine and sinusoidal geometrical structures and presented that dean vortices were formed on each bend and these were responsible for efficient fluid mixing and large rates of heat transfer without a large pressure drop penalty.

Mohammed et al. [11] compared thermal performance using step, zigzag and curvy microchannels of the same cross-sectional area with rectangular and wavy channels. They presented that heat transfer coefficient was the highest for zigzag microchannel as compared to other shapes.

Duryodhan et al. [12] examine the combined effect in a converging and diverging microchannel. They noticed that converging microchannel had more uniform temperature and also had 35% more heat transfer coefficient compared to a diverging microchannel.

In an analysis done by Ahmed A. Y. AlWaaly et al. [13] Main microchannel width is 185 micron which is twice the width of sub microchannels, different positions of hot spot have been investigated and results show good amelioration in the temperature distribution along the chip area. Downstream position gives lower thermal resistance however the upstream hotspot gave more uniform temperature. By using sub microchannel pressure drop increases as compare to without sub microchannel.

2.3.3 Use of cavity, rib and fin: -

As we know that hydraulic diameter of microchannels is very small so the flow inside the channel is found to be laminar flow and Reynolds no. is too low to support turbulence that is required for proper mixing of fluid to enhance heat transfer.

To generate fluid turbulence, such as adding fins and cavities in the channel or sidewalls [14-20], interrupting channel for redevelopment of boundary layer [21-22] and changing channel direction [23-27] giving rise to heat transfer enhancement.

The micro-fins location of channel was investigated [14] and found the thermal performance of upstream fined better than downstream and complete fined in lower Reynolds number. The effect of vortex generators on heat transfer and fluid flow characteristics were investigated experimentally have been used to enhance heat transfer in different geometries such as circular and noncircular ducts. They can take various forms such as protrusions, wings, inclined blocks, winglets, fins, and ribs [28-29]

Behzad Osanloo et al. [30] has done numerical investigation on performance enhancement of double layer taper channel MCHS. It was found that due to formation of boundary heat transfer reduces but in converging channel velocity of fluid increases that augment heat transfer. when convergence angle varies from 0 to 4-degree heat transfer increases after that due to rise in pressure drop performance reduces.

Chai et al. [31] improved the heat transfer performance of straight microchannel by introducing staggered rectangular rib that allow the mixing of hot and cold fluid.

Li et al. [32] used vertical Y shaped bifurcation plate at various location inside microchannel and found enhanced heat transfer at optimized angle of bifurcation at 90 degree.

Nor Haziq Naqiuddin et al. [33] has done numerical analysis of geometrically graded MCHS and observed that with the same mass flow rate of water, geometrically graded micro-channel performed better than the straight channel with an average temperature of 69.6 ^{o}C.

Pankaj Srivastava et al. [34] performed a numerical study on convergent-Divergent MCHS with or without rib and cavities. performance was evaluated on the basis of thermal resistance, friction coefficient and max. temperature. They observed reduction in overall thermal resistance up to 40 % with uniform temperature distribution in MCHS with ribs and cavities.

H. Kamal and A. Dewan [35] studied multi-channel effect due to transvers microchambers and analyzed that use of transvers microchamber not only increase Nusselt no. but also reduce pressure drop.

Ihsan Ali Ghani et al. [36] have studied numerically the hydrothermal performance of MCHS with secondary oblique channel and rectangular rib in alternative direction and found that MCHS with secondary oblique channel (MCHS-SOC) and rib gave 50% less pressure drop as compare to microchannel with ribs only.

3 RECENT STUDIES: -

Ergin Bayrak et al. [37] has executed numerical study on different symmetric and asymmetric configuration of cavity and ribs in MCHS. Lowest pressure drop was found in microchannel with Asymmetric cavity and highest heat transfer was found in microchannel with symmetric cavity and rib.

Mehdi Bahiraei et al. [38] evaluated the effect of hybrid graphene-silver nanofluid in MCHS employed with Secondary channel and Ribs. They mentioned that increase in pressure drop due to presence of ribs, was compensated by secondary channel effect. It was also observed that increase in concentration of nano particle from 0 to 0.1% at Re= 100 enhance heat transfer by 17%.

Saber Deldar et al. [39] have investigated thermohydraulic characteristics of MCHS employed with different convex/concave groves in MCHS.it is observed that At the Reynolds number less than 100, all types of complex grooves have almost the same characteristics. at the Reynolds number more than 100, the grooves with concave curvatures have the highest values of heat transfer characteristics while the grooves with convex curvatures have the best overall hydrothermal performance.

Lei Chai et al. [40] investigated on converging diverging ratio and spacing of triangular rib for both aligned and offset arrangement. They also analyzed effect of geometry and configuration of triangular ribs on thermohydraulic properties. They found that for Re=187 to 715 MCHS with different aligned triangular ribs show 1.03-2.01 times higher heat transfer and 1.06-9.09 times higher pressure drop.

DETAILS OF AVAILABLE RESEARCH ON MCHS

Sr. no.	Author name	Channel Geometry	Nature of Study	Coolant used	Findings
1	T. Bello-Ochende et al [2]	Rectangular	Numerical	Water	Optimal aspect ratio is function of pressure drop and solid volume fraction.
2	V Sarath Teja [7]	Rectangular, triangular, pentagonal and circular	Numerical	Water	Rectangular microchannel heat sink gives better volumetric heat transfer coefficient 0.64 W/cm3K in counter flow.
3	R. Vinoth et al. [8]	Trapezoidal, square and semi-circle	Experimental	Water and Al_2O_3-water Nanofluid	Improvement in heat dissipation 3.13% and 5.87% for water and NF respectively and Higher Pressure drop through trapezoidal channel than another channels.
4	Rosaguti et al [9] [10]	Serpentine and sinusoidal Channel	Numerical	Water	The heat transfer performance was greatly enhanced over straight channels with the same cross section and the pressure drop is much smaller than the heat transfer enhancement.
5	Mohammed et al. [11]	Step, Zigzag and Curvy channel	Numerical	Water	Heat transfer and pressure drop both are higher for Zigzag microchannel heat sink.
6	Duryodhan et al. [12]	Converging-Diverging channel	Numerical	Water	Converging MCHS has uniform temperature and 35% more heat transfer than diverging channel.
7	Ahmed A. Y. AlWaaly et al. [13]	Sub microchannel at different location along channel	Numerical	Water	Improved temperature distribution and lower thermal resistance in downstream position with significant pressure drop.
8	Yadav V et al. [14]	Micro-fin inside channel	Numerical	Water	Better thermal performance in upstream finned than downstream and complete finned.
9	Ebrahimi et al [28] Ahmed et al. [29]	Vertex generator of various shape	Experimental and numerical	Water	Augmentation in heat transfer and pressure drop. Rise in average temperature of fluid.
10	Behzad Osanloo et al. [30]	Double layer tapered MCHS	Numerical	Water	Thermal performance improved and reduced temperature gradient at bottom wall of channel.
11	Chai et al. [31]	Staggered rectangular rib in side channel	Numerical	Water	Enhanced mixing of hot and cold fluid by reinitiating boundary layer.

12	Li et al. [32]	Y shaped bifurcation plate in MCHS	Numerical	Water	Better thermal performance than straight MCHS.
13	Nor Haziq Naqiuddin et al. [33]	Geometrically Graded MCHS	Numerical	Water	Greater performance than straight MCHS with same mass flow rate and cross section of channel.
14	Pankaj Srivastava et al. [34]	Convergent-divergent microchannel with rib and cavity.	Numerical	Water	Reduction in overall thermal resistance up to 40%
15	H. Kamal and A. Dewan [35]	Transvers microchamber	Numerical	Water	Increase in Nusselt no. with reduced pressure drop.
16	Ihsan Ali Ghani [36]	Oblique secondary channel with rib	Numerical	Water	Reduction in pressure drop up to 50% as compare to ribbed MCHS.
17	Ergin Bayrak et al. [37]	Symmetric and asymmetric configuration of ribs and cavity	Numerical	Water	Microchannel with symmetric cavity and rib has best overall performance.
18	Mehdi Bahiraei et al. [38]	MCHS with secondary channel and rib	Numerical	Graphene silver Nano fluid	increase in concentration of nano particle from 0 to 0.1% at Re= 100 enhance heat transfer by 17%.
19	Saber Deldar et al [39]	Convex and concave groves in MCHS	Numerical	Water	Grooves with concave curvatures have the highest values of heat transfer characteristics while the grooves with convex curvatures have the best overall hydrothermal performance
20	Lei Chai et al. [40]	Converging - diverging configuration with triangular rib	Numerical	Water	Aligned triangular ribs show 1.03-2.01 times higher heat transfer and 1.06-9.09 times higher pressure drop
21	Yunfei Yan et al. [41]	Bionic Y shaped fractal network	Numerical	Water	The thermal resistance of thermally optimized model reduced and showed excellent heat transfer.

4 PROBLEM FORMULATION

In the literature survey we found that so much work had been done to increase the heat transfer rate in microchannel heat sink but no work has been done on employing mixture of coolant commercially available in market (other than nanofluid) for liquid cooling of electronic devices with new design of micro channel heat sink. In my work I am trying to represent the comparison between new and conventional design of MCHS with use of different mixture of coolant fluid by considering various parameter e.g. Availability, working temperature range heat transfer rate and pressure drop etc.

5 CONCLUSIONS

In all above-mentioned literature work, there are various designs of MCHS with many heat augmentations geometric modification. These designs have been developed to reinitialize boundary layer formed along the channel length that reduced mixing and heat transfer from channel wall to fluid.

Use of ribs and cavities interrupt the flow of fluid that increase heat transfer and pressure drop significantly, to overcome this secondary channel or secondary microchambers are employed.

In all mentioned work water and Nanofluid used as coolant and they have their own limitation of hydrothermal and economical aspects.

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