Multi-Layer Micro Channels System: Interpretation and Developments

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Abstract

During the last three decades the concept of the traditional cooling systems was modified to include single, double, and multi-layer micro channels. The new studies, applications, fabrication, and research focus on four main areas: the geometrical shape of the micro channels, the number of stacked layers, the type of the coolants, and the heat performance optimization. The previous studies have shown a significant reduction in the power consumption as the optimization is accomplished. In this paper, a semi-review for the previous works is provided, an attempt to interpret the nature of the work done, and show another trial for optimization. In this study, water was used as a coolant agent, stacked multi-channel was adopted, and thermal resistance network was calculated.The heat sink under consideration is a rectangle of width W and length L. The thickness H_{sub} of the base of the micro-channel is 100 [μm] while the depth H_c of the micro-channel is 500[μm], both kept constant for all future optimization cases.

Keyword:stacked, micro-channel heat sink, optimization, thermal resistance, genetic algorithm.

1. Introduction

The developments to modernize the cooling systems focus on two important central issues: maximizing the heat performance and minimizing the equivalent heat resistance of the micro channel network. The journey to achieve these two important issues has started almost three decades ago. Researchers have implemented new technology for cooling system by utilizing the concept of micro channels [1, 2, and 3]. The type of the coolant fluid was originally water [1], then air [2], and a mixture of water-air [3]. The shape of the heat sink was also a subject of investigation. The rectangular shape [4, 5, 6] is the most useable shape but other researchers have adopted square shape [3, 7] while others have used other shapes [8, 9]. In order to increase the ratio of the surface area to the volume, researchers have found that the single layer [1, 2,3,4,5,7,8,9]has little improvement of the heat performance while two layers [10,11,12,13] and multi layers micro channel ,as shown in Fig.1 has shown much better heat performance ,[14,15,16,17] . OfThe central point in the research work was the minimization of the total resistance which, in turn, results in maximizing the heat performance.

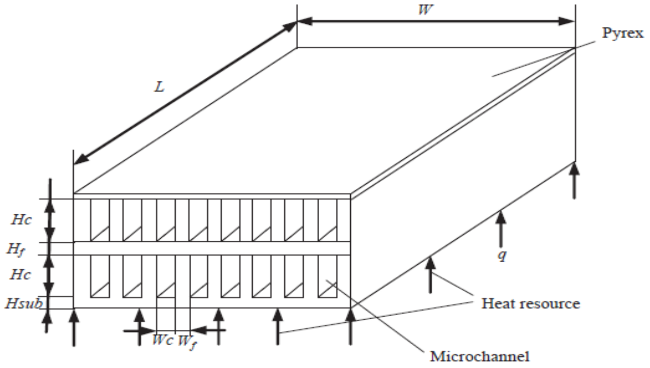

Fig.1 A schematic of the stacked (multilayer) rectangular micro channel heat sink [13]

The developments of these researches focus on how each researcher chose the correct parameters in order to achieve the maximum heat performance by manipulating the parameters such as the type of coolants,the aspect ratio (the channel width to wall width, $\alpha = \mathrm{H_c}/\mathrm{W_c}$) [14], the number of the layers [15], the shape of the heat sink [16], and finally the average speed of the fluid being used in the system.

2-Heat Performance Analysis

To understand the concept behind these developments, researchers have agreed on one issue: calculating the equivalent thermal resistance network of the stacked (multilayer)micro channel system as shown in Fig.2. Someof the typical work performed byother researchersis summarized in Table 1. Readers can see how the equivalent thermal resistance network was developed through the years of (2003)until (2012). The table shows the correlation, differences, and points of agreement. The current study, the last row in the table, has its own share of these developments.

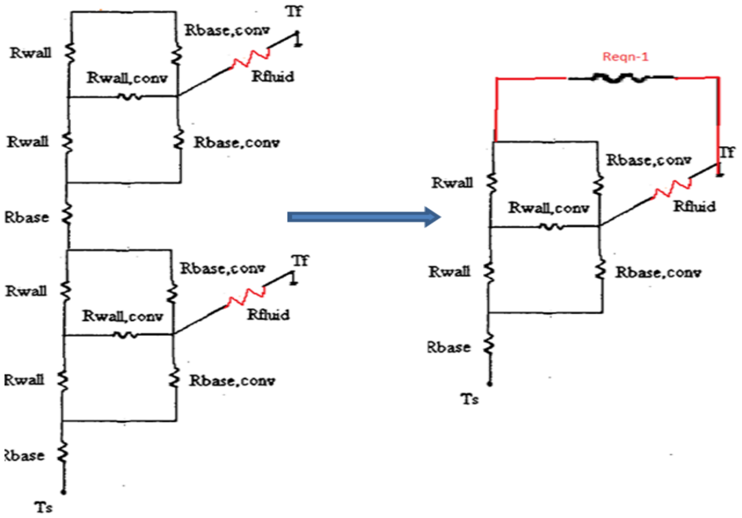

Fig.2. Multi –layer heat sink: thermal resistance network for nlayers

Table (1)Description ofEquationfor Thermal Resistance network(R)

Authours	**Channel geometry Materials , Coolant types**	**Nature of the work, method Analysis**	**List out all assumptions devices**	**Description of Equation for Thermal Resistance (R)**
Baodong Shao, Heming Cheng (2012)	L×W=6mm×6mm, and fin are 196 and 50[µm] double-layer,---deionized water	Optimization and Numerical Simulation (CFD) software& adaptive GA	cool a chippower is 200[W] heat flux is 556[W/cm^2]	$R_{total} = \frac{\{R_{base} + [R_{base,conv} \| (R_{wall} + (R_{wall,conv} + R_{base,conv}))] + R_{fluid}\} R_{fin}}{\{R_{base} + [R_{base,conv} \| (R_{wall} + (R_{wall,conv} + R_{base,conv}))] + R_{fluid}\} + R_{fin} + R_{fin,}}$
N. Lei, P.Skandakumaran, A.Ortega (2006)	Square channel copper, water as coolant.	Experiments and Modeling Single-Phase flow one-dimensional, simulations using CFD	electronic Assuming an isothermal condition systems	$R_n = \frac{R_{base}}{2N} + \frac{R_{base,conv} \| (R_{wall} + (R_{wall,conv} \| (R_{wall} + (R_{n-1} \| R_{base,conv}))))}{2N}$
P.Skandakumaran, A.Ortega, T. Jamal-Eddine, R.Vaidyanathan (2004)	SiC micro channels with diameter of order 100 [µm] liquid cooled .water ,siliconwafers	three-dimensional Modeling and Experimental	Fixed overall flow rate, IC electronics Assuming an isothermal condition at the base of the fluid	$R_{eq,n} = R_c + R_f + R_{base} + (R_b + R_{fin} + R_d) \| (R_a + R_o)$
Xiaojin Wei Yogendra Joshi(2004)	water as coolant area 10 mm by 10 mm a height in the range 1.8 to 4.5 [mm] (2–5 layers) copper, silicon carbide or diamond rectangular duct	Numerical simulations using a computationally efficient multigridmethod, laminar channel flow. Flow rate in the range (50ml/min)to (400ml/min)	thermal performance simplified thermal resistance network Analysis one - dimensional heat transfer at the base and the fin. of each layer	$R''_{\mathrm{tot}} = R''_{cd} + R''_{\mathrm{conv}} + R''_{cp}$ where $R''_{cd} = t/K_s$ $R''_{\mathrm{conv}} = (W_c + W_f)/(h \cdot W_c + 2 \cdot h \cdot \eta_f \cdot H_c)$ $R''_{cp} = (L \cdot (W_c + W_f))/(\rho \cdot C_p \cdot H_c \cdot v_m \cdot W_c)$
Xiaojin Wei and Yogendra Joshi(2003)	1 cm x1Cm, Water, silicon, thickness of the silicon is 500 [µm], upper bound of the channel depth is set at 400[µm] .	Optimization, The aspect ratio, fin thickness and the ratio of channel width to fin thickness are the variables to be optimized,	Pumping power per unit area is 0.01[W/cm]. pressure is limited to be less than 4[bar] (400 000 Pa), flow rate is limited to be 1000[ml/min] (1.67x10^{-5}m^3 /s)	$R''tot = 3.53 \left(\frac{\mu f Re}{Nu} \frac{L^2}{K_f K_s^2 \rho^2 C_p^2 \dot{Q}''} \right)^{0.2}$
Current study	LxW=30mmx30mm, Water, silicon,The thickness of the base of the micro-channel is H_{sub} =100 [μm] while the depth of the micro-channel is H_c =500[μm].	Minimization of the overall thermal resistance, multiobjective optimization. The multi objective genetic algorithm (MOGA) programming procedure will be used to do the optimization design of the configuration size of the micro-channel heat sinks.	The aspect ratio, fin thickness, channel width and the ratio of channel width to fin thickness are the variables to be optimized ,	$R_{tot\,n} = R_c + R_f + R_{base} + \frac{(R_b + R_{wall} + R_d)(R_a + R_o)}{R_b + R_{wall} + R_d + R_a + R_o}$ $R_{tot\,n=1} = R_{base} + R_f + \frac{(R_{wall} + R_d)(R_a + R_o)}{R_{wall} + R_d + R_a + R_o}$

The need for cooling is on the rise –the matter that positively increases the demand for more energy consumption. Scientists and engineers are tirelessly searching for methods to minimize the energy consumed for cooling. The research focuses on developing an optimization technique by utilizing micro electromechanical systems (MEMS) which are equipped with very large-scale integration (VLSI) technologies and by creating devices associated with micron miniaturization. The micro-channel heat sink was then developed as a potential solution to this problem as the device is fabricated with a high surface area to volume ratio for better capabilities compared to the conventional cooling techniques to meet these requirements.

Historically, in1981byTuckerman and Pease [1] worked on the effectiveness of single layer micro channels of 50 [μm] width and a 300 [μm]and water as a coolant. Their findings have shown that the maximum heat flux was found to be 790 [W/cm^2], and themaximum temperature difference between substrate and inlet water was71[^{0} K] and the pressure drop across the micro-channelswas 31[Pa].The finding could be considered as humble results. In1984, the air as a coolantwas replaced Goldberg [2]whoconstructedand tested his new device at different fin thickness by manipulating the ratio (W_{fin}/W_{ch}) and the air flow is restricted to laminar at 30 [L/min] (50 cm^3/s). The findings have shown that the design with the largest pressure drop and smallest channel width yields the smallest thermal resistance. A third development was achieved in 1985by Mahalingam[3]constructing a micro channel heat sink attached to a square silicon substrate of 5[cm]side using water and air as coolants at flow rates of 12 [cm^3/s] and 63[cm^3/s] .

The most recent studies in this field have focused on improving the mathematical model technique as proposed by Quadir*et al*.[4]then Qu and Mudawer [5] whoanalysed heattransfer characteristics in a rectangular micro channel heat sink using water as the cooling fluid,In 2004Kandlikar*et al*.[8] who performed a series of studies on mini channels and micro channels liquid cooling technology, and in2005Liu and Garimella[9]has introduced modelling approaches to minimize the complexity analysis levels for the convective heat transfer in micro-channels.

The optimization of the heat performance is the core element in this type of research. As the optimization techniques have passed through many levels, 1n 2004 YogendraJoshi*et al.* [14, 15] wasstudied of stacked (multilayer) micro channel heat sink and developed to evaluate the overall thermal performance, the study point out that reduction in thermal resistance can be completed by optimizing the channel configuration.in 2006 P.Skandakumaran*et al*. [17] developed a simple thermal resistance network model for both single and stacked(multilayer) heat sinks, Numerical simulation using CFD were performed and compared with experimental results . The mostrecent study is 2007by Shao *et al*. [7, 16],who developed a new method for optimization by utilizing the cross-sectional sizes of the micro-channels at the heat flux of 278[W/cm^2).They optimized the configuration sizes of micro channels cooling heat sinks using the thermal resistance network model with CFD method for simulation. In 2011 Levac*et al*. [12]proposed a comparative study at different Reynolds number for parallel-flow and counter-flow layouts. In a very recent study, in 2013 Shao *et al*. [6]have optimized the structural sizes of multi-layer rectangle micro-channel heat sink by considering both the thermal resistance and pressure drop as main function based on Sequential Quadratic Programming (SQP) method.

3. Conclusion

Throughout this paper, a quick review for previous work has shown that all researchers since (1981) have focused on finding the equivalent resistance of the network at hand. The developments since then have established the concept of calculating the heat resistance and then the heat performance. The optimization of this heat performance depends on several factors amongst them the equivalent resistance, the shape of the micro channel, the type of the flow and the fluid, and the geometrical shape of the channel. This study has contributed a new equivalent resistance of the system which will serve as pivoted point in future work .The dimension of the heat sink is 30X30[mm] and the thickness of the micro channel is 100[μm] and the depth of the micro channel is 500 [μm].

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