Testing of Copper Based Microchannel Heat Sink Inspired by Leaf Venation Pattern for Electronic Cooling

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***Abstract*— A number of microchannel heat exchanger (MCHS) designs are an alternative to dissipate the large heat fluxes generated inside electronic devices. Natural leaf patterns based microchannel heat sinks are the area of current interest due to combination of innovative cooling technology for large amount of heat from a small area and attaining the uniform temperature distribution condition. Branching in microchannel causes the hydrodynamic boundary layer development to be reinitialized at the leading edge of each secondary channel; effectively decreases the boundary layer thickness, enhances the heat transfer performance and incurs negligible pressure drop penalty. Its cooling effectiveness is compared with conventional straight microchannel heat sink through experimental and numerical approaches for the Reynolds number ranging from 300 to 600 with excellent agreement.**

Keywords— Microchannel; Leaf Venation; Electronic Cooling; Micro Heat Exchanger;

I. INTRODUCTION

Due to recent advancements in computing technology the chip level heat fluxes have gone up tremendously and heat fluxes are expected to fast exceed 100 W/cm2. High heat fluxes are also found in opto-electronic equipments, high performance super computers, power devices, electric vehicles and advanced military avionics. Massive fluctuations of temperature in addition to huge spatial variations of temperature in the equipment become responsible for malfunction and eventual breakdown of the equipment. The purpose of thermal design is to create and maintain throughout the equipment a temperature distribution having confined variation around a moderate degree. Thus, increase in performance and operating speed causes increase in generation of heat. Today, the most widely used cooling solution for computer systems is air cooling. In this method, heat is removed from the microchip by using a metal heat sink and a fan. Air cooling has many advantages like low cost, high reliability and good compatibility with microelectronic environment. On the other hand, it has low power dissipation capacity and some other disadvantages like fan noise. The main concern is the low heat flux limits air cooled heat sinks which results in extreme heat flux values occurring on “hotspots” can reduce the chips operation performance and life. The resulting rise in temperature affects the reliability of chip as it is working at higher temperature than the desired operating range.

II. IMPORTANCE OF MICROCHANNEL

Micro heat exchangers are becoming an important area of interest in many fields of developing technology that require compact high heat energy removal solutions. Fields such as MEMS, microelectronics, biomedical, fuel processing, and aerospace are all pushing the limits of thermal control and are finding ways to make smaller devices with higher heat flux potential requiring more efficient smaller heat exchangers to cool their key working components.

The microchannel can be defined as channel with hydraulic diameter in the range of 200μm to 10μm where hydraulic diameter (Dh) can be defined as the ratio of four times area to the perimeter. The microchannel increases the surface area to volume ratio enormously; therefore, the overall thermal resistance of the heat sink decreases. The idea of using very small channels comes from the basic heat transfer equation:

$$Q = U \times A \times \Delta T$$

Where Q is the rate of heat transfer, U is the overall heat transfer coefficient, A is the surface area and ΔT is the temperature difference. In order to increase Q with a small temperature rise, one must increase the UA product. This can be achieved by increasing the surface area; but, that is not always possible since many of the

applications have strict volume restrictions.
For large increases in U value, the convective heat transfer coefficient (h), should be increased while h depends on the Nusselt number (Nu) which changes with flow properties. For fully developed laminar flow conditions;

$$Nu = hD/k$$

Where Nu is the Nusselt number and it is constant, D is channel hydraulic diameter and k is the thermal conductivity of the coolant. The heat transfer coefficient is very high since it increases inversely with the channel hydraulic diameter for a constant Nusselt number. The available surface area is also large. Many of the modern microchannel heat sink designs for electronic cooling applications use liquids (mainly water) as the coolant and provided with arrangement of the microchannel parallel to each other. There are both single phase and two phase solutions for electronic cooling but in two phase cooling temperature range is greater than that of safe operating range of the electronic device (70ºC) and it also results in large thermal stresses. So study of microchannel is restricted to the single phase cooling.

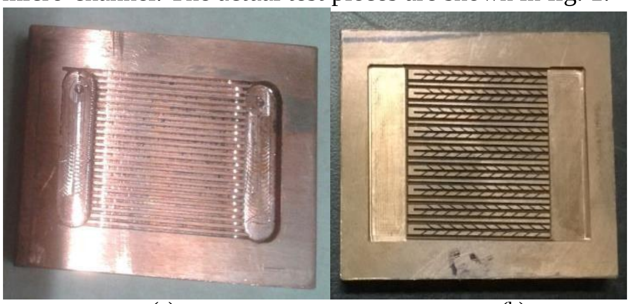
A. Leaf pattern heat sink

The urge of high heat transfer from microchip has led to further exploration of MCHS for passive augmentation. Researchers have investigated MCHS with conventional straight microchannels. However, in parallel micro-channel heat sink, the temperature profile in the electronic device to cool, presents non-uniform behavior. That behavior shows a specific pattern: a low temperature at the zone where the fluid is entering the heat sink, increasing along the channel longitudinal direction until reaching a maximum temperature at the outlet zone of the channel which results in hot spot. Therefore, the temperature field may produce thermo- mechanical stresses which could reduce the lifetime of the system.

One source of inspiration to achieve criterion of uniform temperature distribution can be obtained from natural forms of leaf. Those forms present a general appearance: a main channel which decreases its hydraulic diameter and branches out at a specific position into two or more channels with smaller hydraulic diameter. These structures can be manufactured in order to create channel with specific dimensions which can distribute a specific working fluid in all the substrate. Theoretically, this way to create micro-channel heat sink could increase the fluid velocity, specifically at the last section of the channel. With this, it is expected to improve the overall convective coefficient, distributing more evenly the temperature profile on the device. Thus, it is expected that leaf pattern micro-channel heat sink results in better uniform temperature distribution over the entire surface, compared to the parallel micro-channel heat sink. So it is necessary to design and fabricate the leaf pattern heat sinks.

III. EXPERIMENTAL SETUP

In order to study the heat transfer and fluid flow within a microchannel heat sink, a copper test piece is manufactured. The microchannel (conventional and leaf structured) which has the same dimensions as that of the one used in Numerical simulation are fabricated using LASER of 25×25×5 mm dimension at Print Tech, Navi Mumbai. The test microchannel heat sink has a cover plate which is made from a transparent polycarbonate acrylic sheet and is bolted to the copper heat sink. The copper heat sink was heat insulated at the back by an asbestos sheet covered with glass wool packaging. For the experimental investigation 3 test pieces are manufactured. Experiments are carried out on the heat sinks with conventional straight micro-channel and leaf structured micro-channel. The actual test pieces are shown in fig. 1.



(a) (b)
Fig. 1 Experimental test pieces (a) conventional straight and (b) leaf pattern heat sinks

The experimental setup as shown in fig. 2 consists of water reservoir, pump, DC power supply, temperature indicator for inlet/outlet temperature recording, K-type thermocouples and test section where it holds the test piece assembly. During the test, de-ionized water is pumped from a liquid reservoir into the test section through the flow loop using a pump and flow rate is measured using flow meter. Temperature measurements are obtained at the inlet and outlet plenum of the test section as well as below the channel surface of the test piece using K-type thermocouples respectively. A pre-calibrated digital pressure gauge is used to measure the pressure cross the microchannel. The test section is heated using electric heater by supplying power through dimmerstat from 25W to 45 W and measured by digital ammeter and voltmeter.

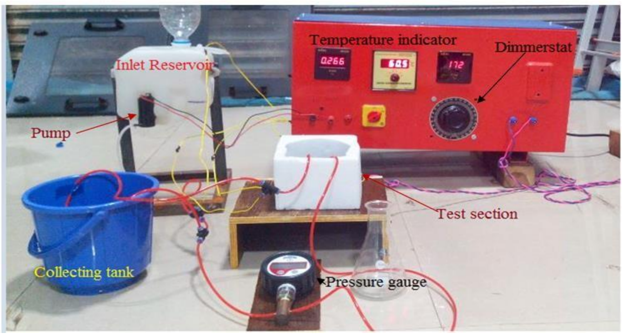


Fig. 2 Actual experimental setup for analyzing heat transfer performance of MCHS

IV. THERMAL PERFORMANCE OF LEAF PATTERN MCHS

After the test section is assembled and calibrations are completed, the pump is switch on and the desired flow rate within the flow loop is set. When the flow rate and inlet fluid temperature are stabilized, the power supply to the heaters is set to the test value. Steady state is reached after about 30 to 50 minutes in each test run when all the temperature readings are within ± 0.1 °C for about 2 minutes. Steady state readings from the thermocouple, pressure gauge and flow rate are recorded throughout the experiment. The flow rate is then increased for the next test, and the experimental procedure repeated. Experiments were conducted at flow rate ranging from 150 ml/min to 250 ml/min and heat input is varied from 25 W to 50 W. The experimental observations are presented in Table 1. Table 1 also shows the variation of the water outlet temperature with mass flow rate. The heat transfer rate increases as water mass flow rate increases. The table also shows that the outlet water temperature decreases as water mass flow rate increases.

Table 1: Experimental observations for Conventional and Leaf pattern MCHS

Heat Input, W	Mass flow rate, (m) kg/s	Tfi °C		Tfo °C		Pressure Drop ΔP, bar	
		*Conv**	*Leaf*	*Conv**	*Leaf*	*Conv**	*Leaf*
45	0.000277	26.9	28.5	29.8	30.8	120	180
	0.000370	28.6	28.7	30	30.8	240	440
	0.000462	28.6	27.1	30.2	28.8	380	560
35	0.000277	28.6	28.6	30.5	30.4	140	200
	0.000370	28.1	29.6	30.3	31.5	220	440
	0.000462	28.8	28	30.9	29.3	380	600
25	0.000277	28.9	28.7	29.4	29.8	140	200
	0.000370	28.1	28.5	29.6	29.5	240	420
	0.000462	28.8	28.5	30.4	29.4	340	560

Figure 3 shows the heat transfer enhancement at different Reynolds number for the conventional straight channel and leaf pattern channel. The heat transfer enhancement (ENu) is defined as the average Nusselt number of the leaf pattern channel divided by that of conventional straight channel .It is defined in the following formulas:

$$E_{Nu} = \frac{\overline{Nu}(Leafpattern)}{\overline{Nu}(Conentionalstraightchannel)}$$

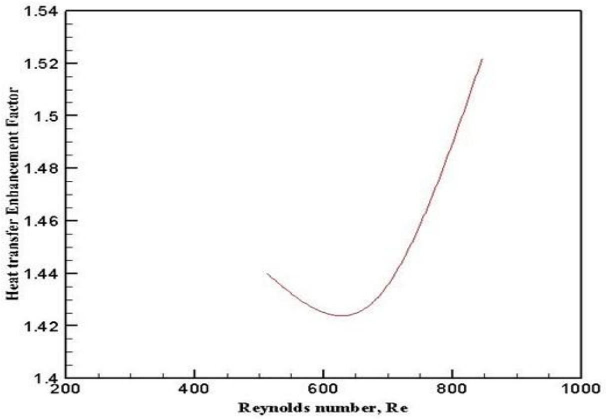


Fig. 3 Heat transfer enhancement for different Reynolds number

As shown by the ENu line, the value is always higher than 1 which implies that the leaf pattern channel is superior to conventional straight channel in heat transfer performance. It should be noted that at higher Reynolds number, the heat transfer performance is improved by about 52% for the leaf pattern microchannel over the conventional straight microchannel.

V. CONCLUSIONS

1. The combined effect of redevelopment of boundary layer and generation of secondary flow results in thinner boundary layer that leads to better heat transfer performance and higher pressure drop. The increased pressure drop was somehow compensated by pressure recovery due to the diffuser effect at each diverging section.
2. The Nusselt number for the leaf pattern microchannel heat sink increases by 33% as compared with the conventional straight microchannel heat sink.
3. The heat transfer performance is improved by 52% for the leaf pattern microchannel over the conventional straight microchannel. This shows that there are significant advantages of the leaf pattern microchannel over the conventional straight microchannel.

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