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Effect of non-uniform heating on the performance of the microchannel heat sinks☆

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ABSTRACT

The present study experimentally investigates the performance of a 2-pass microchannel heat sink subject to non-uniform heating. The size of the microchannel heat sink is 132 mm × 82 mm × 6 mm with a rectangular channel of 1 mm × 1 mm. Three independent heaters having identical size (96 mm × 38.5 mm × 1 mm) is placed consecutively below the microchannel heat sink. Two kinds of manifolds are used for testing of the microchannel, one with a side entrance (type A) and the other with a front entrance (type B). Test results show that both maximum temperature and average temperature rise with the total input power, and this is applicable for both manifolds. For uniform heating condition, the maximum temperature for type B manifold is much lower than that for type A manifold due to a better flow distribution and heat transfer performance. The pressure drop is slightly reduced with the rise of supplied power. For non-uniform heating, the maximum temperature and the average temperature depend on the location of heaters. For the same supplied power with non-uniform heating, it is found that heater being placed at the inlet of the microchannel will give rise to a higher maximum temperature than that being placed at the rear of the heat sink. This phenomenon is especially pronounced when the inlet flowrate is comparatively small and becomes less noted as the inlet flowrate is increased to 0.7 L/min.

1. Introduction

The microelectronic industry has continued to follow the Moore's law of increasing transistor density on a single chip [1]. Hence, the heat dissipation density of a typical chip has risen dramatically since more and more transistors are being packed in a confined area. As a consequence, thermal management exploiting conventional air-cooling becomes insufficient to handle the increasing heat dissipation of the current and future microprocessors. In this regard, single phase liquid cooling for microprocessors has been recognized as an effective alternative for the high flux applications. Liquid cooling employing microchannel design is especially promising for it provides effective heat removal within a limited space. However, there are two major issues in association with liquid-cooled microchannel heat sink. The first is the liquid flow distribution alongside the multiple microchannels and the second problem is inherited with the nature of electronic devices whose heat source is normally non-uniform. The presence of non-uniform heating may substantially raise the temperature for its gigantic spreading resistance.

In recent years, there had been some studies concerning the influence of inlet location on the flow distribution of a liquid-cooled heat sink. For example, Lu and Wang [2] studied five different inlet locations, namely I-type, Z-type,]-type, L-type and Γ-type, on the overall performance of a multiple liquid-cooled heat sink. Their results showed that the heat transfer performance for I-type outperforms other inlet arrangements. Ljubisa et al. [3] designed a microchannel having a splitting flow arrangement which can considerably reduce the pressure drop of the microchannel heat sink.

Since both heat transfer and pressure drop must be considered in optimizing the performance of the microchannel heat sinks. Toh et al. [3] performed a 3-D numerical simulation of the microchannels, and they reported that at lower Reynolds number the temperature of the water increases, leading to a decrease in the viscosity and hence smaller frictional losses. Park et al. [4] numerically examined the effect of rectangular channel size on the performance of microchannels. They found that there were deviations between the experimental and theoretical values of the heat transfer rate in the microchannels, and they proposed an empirical correlation to amend the deviations. Liu et al. [5] use a PIV technique to measure velocity distribution of microchannel subject to five different inlet arrangements, and their measured results are generally in line with the numerical calculation by Lu and Wang [2].

The foregoing results are mainly associated with uniform heating condition. In practical application, the surface heat flux may not be uniform, and this is commonly encountered in typical IGBT/diode high power module. However, relevant researches on this topic are very rare. Lelea [6] numerically investigated the effect of partially heated perimeter on the microchannel. He found that the partial heating together with variable viscosity casted a strong influence on the thermal and hydrodynamic characteristics of the micro-heat

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Nomenclature

D_h	hydraulic diameter, mm
P	supplied power into the heater, W
Pr	Prandtl number, dimensionless
Q	heat transfer rate carried by water coolant, W
Q_{avg}	average heat transfer rate, $Q_{avg} = \frac{Q_{sup}+Q}{2}$, W
Q_{losg}	heat loss through the bakelite, W
Q_{sup}	supplied input to the microchannel heat sink, W
Re	Reynolds number, dimensionless
T	temperature, °C
T_{in}	water inlet temperature, °C
T_{out}	water outlet temperature, °C
x	axial coordinate from the entrance of the microchannel, m
x^+	dimensionless axial coordinate, $x^+_{\text{fully devloped}} = \frac{x}{D_h \mathrm{RePr}}$

sink. Cho et al. [7,8] investigated the cooling performance of the microchannel heat sinks under various heat flux conditions subject to different geometry and header locations. Thermal load is applied to the microchannel heat sinks by nine separate heaters in order to provide a uniform or non-uniform heat flux. Their results indicated that the straight microchannels are less sensitive to the temperature distributions.

As seen, very few researches were concerned with the influence of non-uniform heating on the performance of the microchannel heat sink, yet the experimental data is especially rare. In this regard, it is the objective of this study to provide some experimental data on this subject.

2. Experimental setup

The schematic of the experimental apparatus is depicted in Fig. 1. The test rig is composed of a water cooling loop, a data acquisition system, and a water thermostat. The water thermostat is to maintain a fixed inlet water temperature into the test section. The water loop consists of a centrifugal pump (Iwaki Corp., model MD-20RZ) which delivers water coolant alongside the piping and into the test section. The water pump can provide a volumetric flowrate from 0.1 to 1 L/min. A pre-calibrated rotameter is installed between the water pump and the test section. The uncertainty of the volumetric flowrate is less than 0.005 L/min of the test span. The test sample is a two-pass microchannel heat sink with two different designs of manifold. The manifolds are characterized as long edge (type A) or short edge (type B). The long edge manifold denotes a side inlet entrance which is normal to the main flow direction while the inlet of the short edge manifold is parallel to the flow direction. The size of type A manifold is 10 mm × 102 mm × 21 mm. The size of inlet and outlet manifolds is identical. The size of the type B manifold is 25 mm × 90 mm × 14 mm. Schematic of the flow direction in and out the microchannel for type A and type B manifolds is schematically shown in Fig. 2. The size of the microchannel heat sink is 132 mm × 82 mm × 6 mm and is made of cooper. The rectangular

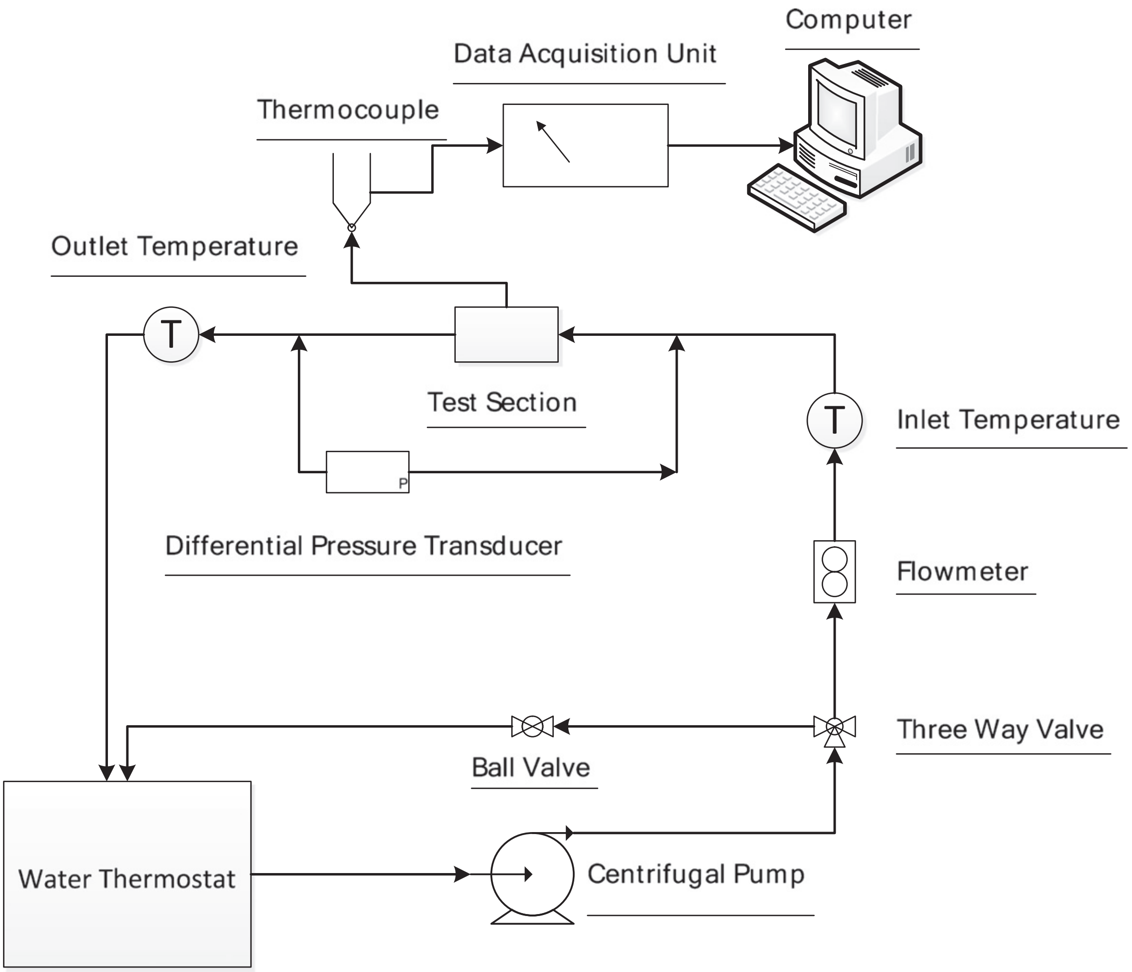

Fig. 1. Schematic of the test setup.