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Influence of channel shape on the thermal and hydraulic performance of microchannel heat sink ☆

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ABSTRACT

Microchannel heat sinks (MCHS) can be made with channels of various shapes. Their size and shape may have remarkable influence on the thermal and hydrodynamic performance of MCHS. In this paper, numerical simulations are carried out to solve the three-dimensional steady and conjugate heat transfer governing equations using the Finite-Volume Method (FVM) of a water flow MCHS to evaluate the effect of shape of channels on the performance of MCHS with the same cross-section. The effect of shape of the channels on MCHS performance is studied for different channel shapes such as zigzag, curvy, and step microchannels, and it is compared with straight and wavy channels. The MCHS performance is evaluated in terms of temperature profile, heat transfer coefficient, pressure drop, friction factor, and wall shear stress. Results show that for the same cross-section of a MCHS, the temperature and the heat transfer coefficient of the zigzag MCHS is the least and greatest, respectively, among various channel shapes. The pressure drop penalty for all channel shapes is higher than the conventional straight MCHS. The zigzag MCHS has the highest value of pressure drop, friction factor, and wall shear stress followed by the curvy and step MCHS, respectively.

1. Introduction

The amount of literature of heat transfer effects on liquid flow in MEMS or in microchannels is vast and growing. In the last two decades, many cooling technologies have been pursued to meet the high heat dissipation rate requirements and maintain a low junction temperature. Among these efforts, the microchannel heat sink (MCHS) has received much attention because of its ability to produce high heat transfer coefficient, small size and volume per heat load, and small coolant requirements. Apart from that, the MCHS cooling concept was first proposed by Tuckerman and Pease [1] in 1981, who pointed out that decreasing liquid cooling channel dimensions to the micron scale will lead to increase in heat transfer rates.

A MCHS is typically contains a large number of parallel microchannels with a hydraulic diameter ranging from 10 to 1000 µm and a coolant is forced to pass through these channels to carry the heat away from a hot surface. Since then, MCHS performances with different types of channel shapes have been studied extensively by many researchers.

Peng and Peterson [2,3] performed experimental investigations on the pressure drop and convective heat transfer for water flow in rectangular straight microchannels. It was found that the cross-sectional aspect ratio had a great influence on the flow friction and convective heat transfer both in laminar and turbulent flows. Philips [4] proposed a method of determining the overall thermal resistance as a function of pertinent variables. He performed a sensitivity analysis to evaluate various parametric effects on his test case and extended the analysis to include larger channel widths of rectangular-shaped microchannels with moderate aspect ratio and for fully developed and developing flows in laminar and turbulent flow regimes. The test sections were fabricated using indium phosphate as the wafer material and water was used as the working fluid. Liu and Garimella [5] conducted flow visualization and pressure drop studies on rectangular straight microchannels with hydraulic diameters ranged from 244 to 974 µm over a Reynolds number range of 230 to 6500. They measured the onset of turbulence through their flow visualization, and they compared their pressure drop measurements with numerical calculations. Their results showed that both conventional turbulent transition and pressure drop correlations are valid on the microscale.

Wu and Cheng [6] studied experimentally the friction factors in smooth trapezoidal silicon straight microchannels with different aspect ratios. They concluded that the *fRe* of liquid flowing in microchannels, having the same hydraulic diameter but with different cross-sectional shapes, can be very much different due to the cross-sectional shape of the channels. Chein and Chen [7] analyzed numerically the fluid flow and heat transfer characteristics in rectangular cross-section MCHS with different inlet/outlet arrangements. They inferred that better performance or uniformities in velocity and temperature can be found in the heat sinks having coolant supply and collection vertically via inlet/outlet ports opened on the heat sink cover plate. Sui et al. [8] reported that significant

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