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Review

The effect of manifold zone parameters on hydrothermal performance of micro-channel HeatSink: A review

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ABSTRACT

Understanding of flow characteristics of microchannel heat sink (MCHS) is a prerequisite for its design. Performance optimization via accurate design of manifold zone and subsequent reduction of the flow maldistribution (MLD) remains challenging. This communication critically evaluates the effects of manifold zone related geometrical parameters including inlet-outlet flow arrangement, design and shape on the hydrothermal performance of MCHS in terms of flow mal-distribution. It is demonstrated that split-flow strategy has a significant impact on the hydrothermal performance enhancement. I-type flow feed with vertical inlet and outlet reveals improved flow distribution than horizontal supply. Furthermore, the reverse flow arrangement of C-type performs better than parallel flow arrangement of Z-type. It is affirmed that for reduced flow MLD the channel area must be smaller than manifold region. Meanwhile, the enlargement of combining manifold region is discerned to improve the flow uniformity. For I-type manifolds with vertical feeding, the rectangular configuration produces better normal flow distribution. Conversely, for axial feeding, the manifold shape alteration is essential to reduce the incoming jet flow. For Z-type manifolds, symmetrical triangular geometry generates superior flow distribution. In the case of a C-type manifold, both dividing triangular shape as well as combining trapezoidal configuration creates better flow distribution. This informative review article is hoped to serve as taxonomy for navigating and understanding the research advancements towards the manifold zone parameters dependent hydrothermal performance of MCHS.

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1. Introduction

In the past few decades, the rapid growth in the integrated circuits (ICs) allowed the miniaturization of remarkably dense high speed electronic technology. Conversely, such miniaturization that provokes the generation of high heat within ICs appears detrimental for electronic performance unless inhibited. According to Moore's law, more heat energy dissipation becomes indispensable because the transistors density nearly gets doubled in every eighteen months [1]. Thus, the development of an effective cooling method becomes a priority. The conventional cooling methods using metal fins and fans remain ineffective for disposing the generated excess heat within IC. Besides, the proposed method must be compatible with the miniaturized size of the ICs.

To overcome such generated heat, intensive efforts are made for developing various microcooling systems including micro-jet impingement, micro-heat pipe, micro-electro-hydrodynamic and microchannel heat sink (MCHS). Amongst different micro-cooling devices, MCHS became promising due to its several notable attributes [2–5]. The provision of large heat transfer surface-to-volume ratio is the primary notion behind MC. The microscopic nature of the channels allows a remarkable reduction in the thermal boundary layer thickness. This in turn diminishes the convective resistance to heat transfer thereby generates high cooling rates. Exceptionally simple operation of MCHS is mainly relying on the machining of several MCs on the rear surface of electronic components. Consequently, the heat generated by these components is efficiently transferred to the coolant via forced convection. Tuckerman and Pease [2] demonstrated that MCHS can efficiently remove the generated heat as much as 790 W/cm^2.

In MCHS, the fluid flow trajectories pass through two regions such as manifold and channel where each region plays a specific role. For instance, the manifold region is responsible for accommodating flow which enters from the inlet port, guiding and dividing the flow between channels, combining the fluid that exits from channels and guiding through the exit port. Thus, this region maintains the flow distribution between channels. Experimental data on single MC revealed good agreement with theoretical results on friction factor [6–8]. However, experimental results for multiple MCs are deviated from theoretical estimates on pressure drop and friction factor [9,10]. Webb [11] and Kumaran et al. [12] acknowledged that such discrepancy is due to the effect of MLD in parallel channels aroused from pressure variation in dividing and combining manifolds. Thus, the presence of flow MLD that is accountable for the temperature MLD often leads to the formation of localized hot spots in the device [1]. Mueller et al. [13] reviewed the causes of MLD in heat exchangers and identified several design factors including poor manifold design, fabrication tolerance and inlet-outlet flow arrangement that contribute towards flow MLD. Several experimental and numerical studies are performed to determine the effect of manifold zone on the hydrothermal performance of MCHS. Various modified schemes such as manipulation of inlet-outlet flow arrangements, manifold dimensions, and manifold shape are proposed for reducing the flow MLD in MCs. Despite all such exploration an optimized design of MCHS is far from being achieved.

This article provides a comprehensive review of the recent progress and future trends regarding the modifications of geometrical parameters in the manifold zone of MCHS to achieve improved hydrothermal performance (HP). Influences of various manifold shapes, design, and inlet-outlet flow arrangements on the flow MLD of MCHS are critically assessed. This paper is organized as follows. Section 2 underscores the main idea behind the manifold in terms of structures, flow distribution, and approaches for predicting the flow distribution in MC. Section 3 outlines the effects of different arrangements on the flow distribution and HP. Section 4 describes the impact of manifold dimension such as the ratio of manifold length to width, ratio of cross-section areas of combining manifold to dividing manifold and finally the ratio of the channel areas to the area of the dividing manifold. Section 5 explains the effect of manifold shapes on normal flow, parallel flow, and reverse flow. Section 6 concludes the paper.

2. Manifold region

2.1. Concepts of manifold

A manifold is a wide channel with a porous side wall which is attached with multiple narrower channels at right angles as depicted in Fig. 1. Each manifold works as a distributor or collector of the fluid flow into and from such channels under a pressure difference [5,14–16]. According to Wang [17], the manifold structures can be classified into two types (Fig. 1 such as bifurcation and consecutive as briefly described below [18,19].

2.2. Manifold structure

2.2.1. Bifurcation type

The bifurcation structure is a branched channel in the form of a tree, where the diameter and length of channels are gradually reduced in the flow direction (Fig 1a). In this type the flow distribution under different flow rates does not change even at high Reynolds number. Although this kind shows good performance but the design is very complex. It requires a high precision manufacturing to ensure equipartition between branches and avoidance of port blockage. Besides, a high pressure drop often occurs due to many turns and ports. Thus, it is unsuitable for reduced pressure drop related applications [17,19].

2.2.2. Consecutive type

Generally, a consecutive manifold (Fig 1b) is used for multiple applications because of its simplicity and relatively lower pressure drop compared to bifurcation type. In this type the main flow