International Journal of Thermal Sciences 89 (2015) 305–313

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Analysis of performances of a manifold microchannel heat sink with nanofluids

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A R T I C L E I N F O

Article history:
Received 29 March 2014
Received in revised form
10 November 2014
Accepted 14 November 2014
Available online

Keywords:
Manifold microchannel heat sink
Nanofluids
Entropy generation

A B S T R A C T

Hydraulic and thermal performances of a manifold microchannel heat sink (MMHS) with and without nanofluids as working fluids have been investigated by a finite volume method. Effects of volume fraction, particle diameter of nanoparticles, and Reynolds number on the Nusselt number, pumping power, performance index, and entropy generation in a 3D unit cell were evaluated. The results showed that with increasing volume fraction of nanoparticles, Nusselt number and pumping power increase, but total entropy generation decreases. Increasing particle diameter leads to decreasing Nusselt number, pumping power, and performance index, but increasing the total entropy generation. Finally increasing the Reynolds number leads to increasing the Nusselt number and pumping power, but decreasing performance index and total entropy generation.

1. Introduction

With increasing number of parts packed on a smaller and smaller chip area, the heat accumulated inside causes the temperature to rise dramatically. The integration of the transistors blocks the heat from dissipation by conventional air-cooling solutions [1]. As a direct result, the computer chips cannot function very well due to high temperatures, even cause failure. Tuckerman and Pease [2] first proposed and investigated a heat sink with microchannels, along with liquid-cooling approach by using water as the coolant. By consuming *790 W/cm²*, the maximum temperature increased up to *71°C* over the inlet water temperature and a thermal resistance of *0.1 cm² °C/W* was measured with a pressure drop *2 bar*. Harpole and Eninger [3] introduced the concept of manifold and showed the manifold microchannel heat sink could achieve *100 W/cm²* with a pressure drop of *2 bar*. Copland et al. [4] numerically analyzed the manifold microchannel heat sinks and found that the regions of high heat transfer were near the inlet. They also showed that the secondary maximum heat transfer occurred at the base of the microchannel below the inlet and at the top of the microchannel near the exit.

Brunschwiler et al. [5] studied the improvement in heat transfer efficiency by introducing the manifold system and single-phase liquid jet impingement at the top of the chip. They demonstrated a thermal resistance of *0.17 cm²K/W* for a flow rate of *2.5 l/min*, at the pressure drop of *0.35 bar*. Escher et al. [6] experimentally investigated the hydrodynamic and thermal performances of an ultra-thin manifold microchannel heat sink and reported cooling power densities of over *700 W/cm²* for a maximum temperature difference of *65 K* between the chip and the inlet flow. Sharma et al. [7] studied a novel framework experimentally and computationally to determine the optimal operation conditions of water cooled micro-processor chips; they showed that the optimal operating conditions for chip cooling can be achieved via single- or multi-objective approaches.

Another way to improve the performance of microchannel heat sinks is to use nanofluids as coolants. Many studies indicate that adding low volume fraction of nanoparticles to the base fluid leads to significant increase on thermal conductivity of the coolant [8–11]. Li and Peterson [12] conducted an experimental investigation to examine the effects of temperature and volume fraction on the steady-state effective thermal conductivity of two types of nanofluids. It was reported that *6%* CuO–water suspension has higher thermal conductivity up to 1.52 times than the pure distilled water, while *10%* Al_2O_3–water suspension has higher thermal conductivity by a factor of 1.3. Some researchers investigated the convection of nanofluids and found that the use of nanofluids increases the heat transfer coefficient and Nusselt number [13–18]. Heris et al. [19] experimentally, investigated the thermal performance of laminar flow by using CuO–water and Al_2O_3–water

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http://dx.doi.org/10.1016/j.ijthermalsci.2014.11.016
1290-0729/

nanofluids as working fluids. The Nusselt number and Peclet number of both nanofluids increased with increasing nanoparticle concentrations. Mohammadian et al. [20] investigated the laminar forced convection and entropy generation in a counter flow microchannel heat exchanger with and without nanofluids in hot and cold channels and reported that the capability of heat transfer of Al_2O_3–water nanofluids is higher when nanoparticles are used in cold channels.

In this paper, performance of the manifold microchannel heat sink with nanofluids as coolant was compared to the one with water by conducting computational simulation with various inlet velocities, nanoparticle diameters and solution concentrations. The performance index was investigated to evaluate the balance between the hydrodynamic and thermal performance to obtain an overall heat transfer performance. In addition, entropy efficiency of the manifold microchannel heat sink was also investigated. Several objective functions were represented to define optimal operation conditions for nanofluids cooled chip.

2. Physical and mathematical models

The manifold microchannel heat sink in this study is made of silicon. A schematic of the manifold microchannel heat sink is shown in Fig. 1(a). The dash line region illustrates the computational domain of a unit cell of the manifold microchannel heat sink. The fluid impinges into the inlet manifold and divides equally into two streams. Each stream takes away heat from the electronic chip when passing through the microchannels respectively. Fig. 1(b) shows the computational domain of a unit cell of the manifold microchannel heat sink in detail. In order to save computational resources, only half on the inlet to the outlet is modeled. Al_2O_3–-water nanofluid is selected to be the working coolant. The properties of nanofluids, such as density, viscosity and thermal conductivity of the coolant, are functions of temperature, volume fraction, and diameter of the nanoparticles.

Table 1
Geometric dimensions of unit cell of manifold microchannel heat sink.

Symbol	Description	Value (μm)	Symbol	Description	Value (μm)
L_{inlet}	Length of inlet	2000	H_m	Height of wall above manifold	500
L_{outlet}	Length of outlet	2000	H_b	Height of manifold	1000
L	Length of channel/fin	16,000	H_{ch}	Height of channel	1500
W_f	Width of fin	100	H_s	Height of solid base	1500
W_{ch}	Width of channel	100			

A constant heat flux of $Q_w = 55\ W/cm^2$ is applied uniformly to the bottom wall. The top front wall and bottom front wall are adiabatic. At the inlet, a uniform velocity is applied to simplify the problem. The inlet temperature is fixed at 300 K during the entire cooling procedure. The gauge pressure and the gradients of velocity and pressure at the outlet are assumed to be zero. All other faces are considered as walls with non-slip boundary conditions. Symmetric boundary condition is applied on the left-side of the inlet, the front part of the channel and the backsides of both of the inlet and outlet [21]. Other geometric dimensions of unit cell of manifold microchannel heat sink are summarized in Table 1.

It was assumed that the Reynolds number of the flow is in the range of *100–400*, which means that the flow is laminar during the process of water flowing from the inlet to the outlet [7]. Also, it was assume that the low concentration of nanoparticles in the base fluid makes it behave like a single phase fluid and there is no agglomeration or sedimentation.

The continuity, momentum, and energy equations for a steady state flow can be written as:

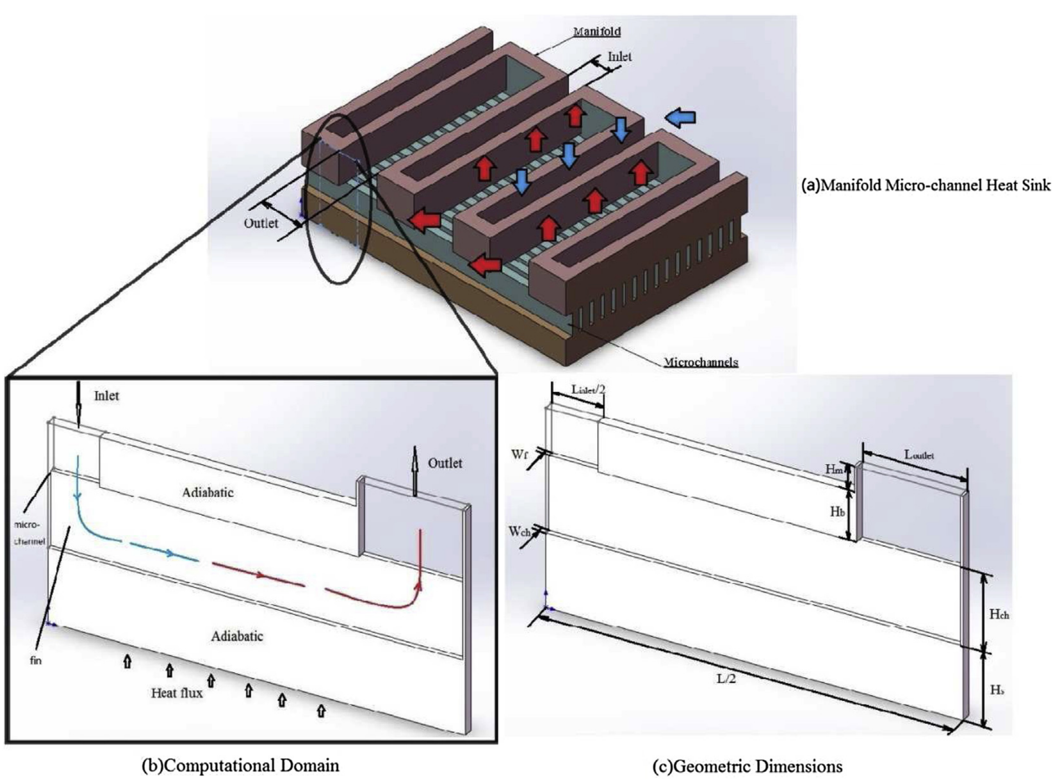

Fig. 1. Physical model.