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Optimization of thermal performances and pressure drop of rectangular microchannel heat sink using aqueous carbon nanotubes based nanofluid

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HIGHLIGHTS

- Optimization of 0.01% weight concentration of aqueous carbon nanotubes based nanofluid as coolant in a rectangular MCHS has been completed using the elitist non-dominated sorting genetic algorithm (NSGA-II) optimization procedure.
- The optimized thermal resistance for the nanofluid is better than that of water particularly at high temperature.
- The reduction in number of channels is very slight, a large quantity of 1 cm by 1 cm MCHS could mean savings in the production cost using nanofluid.

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ABSTRACT

The present work focuses on analytical optimization of a rectangular microchannel heat sink using aqueous carbon nanotubes based nanofluid as coolant. The particles weight concentration used in this study is 0.01%. The density, the thermal conductivity and the rheological behavior of the nanofluid are experimentally investigated in order to evaluate the thermal resistance and the pumping power in microchannel under laminar flow. An analytical approach of optimization scheme was applied; it is compiled from a systematic thermal resistance model as an analysis method and the elitist non-dominated sorting genetic algorithm (NSGA2). The effects of the temperature, the channel aspect ratio, the channel wall ratio and the use of aqueous carbon nanotubes based nanofluid on the thermal resistance and the pumping power are investigated. The optimized results showed that use of the nanofluid as a working fluid reduce the total thermal resistance and can enhance significantly the thermal performances of the working fluid at high temperatures.

1. Introduction

Recent developments in the integrated circuits fabrication technology have allowed to integrate 3–6 billion transistors in a single electronic chip. This enormous number of transistors made these ICs powerful enough to perform multiple functions without any noticeable time delay. However, huge amount of heat (100 W/cm^2 [1]) is generated which rises the ICs' temperature significantly. To ensure better performances of these ICs, it is vital to suppress this temperature rise to its minimum. Since the innovation work by Tuckerman and Pease [2], the microchannel heat sink MCHS attracted great interest in recent years because of its capacity to dissipate a large heat from a small area. Day after day, researchers realized that the basic capabilities of the microchannel heat sinks are not enough sufficient to perform effective cooling of MEMS devices. Therefore, unlimited efforts were devoted to enhance the capabilities of the microchannel heat sinks using different structural material [3–6], different channel geometries [7–10] and different coolants [11–13]. The use of different materials and channel geometries have almost reached to their optimum stage, significant improvement in the overall

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performance of the microchannel heat sinks could not be achieved. However, the working fluids mostly used in microchannel heat sinks are air, water and refrigerants. The properties of these coolants limit their capabilities of heat removals in microchannel heat sink. The basic idea is to improve the thermal performances by changing the working fluid properties [14]. Based on this concept, recent researches focused on the heat transfer enhancement by using nanofluids [15–18]. Nanofluids consist of nanometer-sized particles of metals, oxides, nitrides, or nanotubes dispersed in a base fluid. They have attracted much attention because of their high thermal conductivity and thermal performances compared to pure fluids therefore great potential for heat transfer enhancement [19–21]. In recent years, several investigations have been carried on heat transfer performances of microchannel MCHS using nanofluids. Lee et al. [22] investigated experimentally the effectiveness of alumina water based nanofluid at enhancing heat transfer in microchannel heat sinks. Lelea [23] found by numerical modeling of alumina water based nanofluid in microchannel that the heat transfer enhancement rises as the volume fraction increases or the particles diameter decreases. Teng and Yu [24] studied experimentally the merits and the limitations of aqueous CNTs based nanofluid for cooling system for engine. Chein and Huang [25] investigated the thermal and hydrodynamic performance of a CuO/water cooled rectangular microchannel heat sink for different volume fraction and two specific geometries. They found that the performances were greatly improved for these two specific geometries by using nanofluids as the coolants compared with pure water due to the increase in thermal conductivity of coolant and the nanoparticles thermal dispersion effect.

Mohammed et al. [26] investigated numerically the thermal performances of alumina/water cooled rectangular microchannel heat sink. They found that the nanofluid-cooled MCHS has lower thermal resistance than pure water-cooled MCHS. The thermal resistance value decreases as the volume fraction of nanoparticle increases.

Abbassi and Aghanajafi [27] investigated heat transfer enhancement of a microchannel heat sink with copper water CuO/water based nanofluids. Their results show that the use of nanofluid leads to astonishing heat transfer enhancement in MCHS and this enhancement increases with increasing flow Reynolds number and particle concentration. A similar analysis was performed by Tsai and Chein [28] for MCHS performance using Cu/water and aqueous carbon nanotubes based nanofluids as working fluids. Based on porous media model for the microchannel, they found that the nanofluid can enhance significantly the thermal performances of the microchannel only when the porosity and the aspect ratio are less than the optimum values evaluated under the pressure drops conditions. Bhattacharya et al. [29] found that the use of alumina water based nanofluid improves the microchannel heat sink performances MCHP by reducing fin thermal resistance. Their simulation results show that fully developed heat transfer coefficient increases with Reynolds number even under laminar flow.

Hang [30] performed an analytical study of the viscous dissipation effect on thermal performances of nanofluids in microchannel under laminar fully developed flow. The results show that the Nusselt number is overestimated when the viscous dissipation is neglected.

As reported so far, carbon nanotubes based nanofluids are rarely investigated in MCHS. In most of the works mentioned above, the thermophysical properties are calculated using analytical models. However, many results in published literature are not consistent with others or with the analytical models [31–33]. In the present work, we experimentally characterize the thermophysical properties of aqueous carbon nanotubes based nanofluid. The aim is to optimize the thermal resistance and the pumping power in a rectangular microchannel MCHS under laminar flow using the optimization algorithm developed by Ahmed et al. [34]. This optimization is comprised of a thermal resistance and pressure drop as analysis models and the NSGA-II as optimization algorithm. The effects of the temperature, the channel aspect ratio optimization and the use of aqueous carbon nanotubes based nanofluid on the thermal resistance and the pumping power of the working fluid in microchannel are investigated.

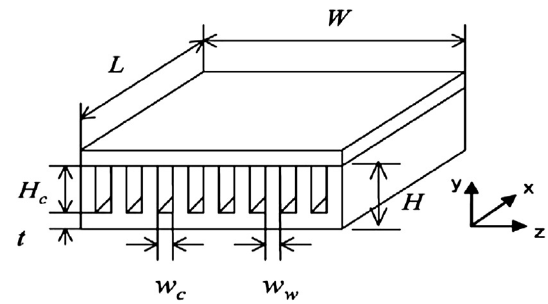

Fig. 1. Schematic drawing of the microchannel heat sink model.

2. Mathematical modeling and validation

2.1. Mathematical model

Fig. 1 shows the geometric configuration of the rectangular microchannel heat sink under consideration. The microchannel heat sink consists of an adiabatic cover plate on the top and n number of parallel microchannels with rectangular cross section. A uniform heat flux (q) was assumed to be applied by a heat generating source from upper surface of the microchannel heat sink with the coolant flowing through the channels.

L, W, H and t are respectively the length, the width, the height and the substrate thickness of the microchannel heat sink. w_c, w_w and H_c are respectively the channel width, the wall width and the channel height.

In the optimization process of the microchannel heat sink, the channel width w_c and the wall width w_w are regarded as variables and the other parameters are fixed as reported in Table 1. w_c and w_w are related to the channel aspect ratio α and the wall width ratio β as follows:

$$\alpha = \frac{H_c}{w_c} \quad \beta = \frac{w_w}{w_c}$$

α and β will be used in the optimization process.

The thermal performance of the microchannel heat sink is evaluated by its total thermal performances defined as the ratio of the temperature difference between the inlet fluid and the maximum outlet surface and the heat flux (q). The total thermal resistance R is calculated using the Equation (1) given by Ref. [34] as:

Table 1
Geometrical parameters of microchannel heat sink.

Parameters	Values
Heat sink width. W (m)	1×10^{-2}
Heat sink length. L (m)	1×10^{-2}
Substrate thickness. t (m)	213×10^{-6}