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Heat transfer enhancement using nanofluids (Al_2O_3-H_2O) in mini-channel heatsinks

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ABSTRACT

This paper presents the heat transfer enhancement characteristics using nanofluid ($Al_2O_3 - H_2O$) as a coolant in mini-channel heatsinks. Heatsinks with three different channel configuration were fabricated and tested for their heat transfer characteristics using nanofluids with two different volume concentrations and distilled water. Effects of channel configuration, coolant flow rate and volume concentration on the convective heat transfer coefficient, base temperature, thermal resistance, and heat transfer enhancement ratio have been reported. Moreover, the thermal and hydraulic performance of mini-channel heat sinks with four different channel configurations has been computed numerically using single phase and two-phase models. Computed results of convective heat transfer coefficient from both single and two-phase models were then compared with experimental results. Results revealed that the convective heat transfer coefficient enhances significantly by using nanofluids in comparison with distilled water. Moreover, predictions of two-phase mixture model were found in close agreement with an experimental model while single phase numerical model was found to have under predicted values of convective heat transfer coefficient.

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1. Introduction

Rapid advancements in microelectronics require equally fast improvements in their thermal management systems, due to their high heat dissipation rates. Performance and lifespan of an electronic device is highly dependent on the temperatures at which its semiconductor junctions are being operated. Thus, to maintain the temperature of a semiconductor device within required limits, dissipated heat is required to be extracted continuously. Thermal management systems involving mini and microchannel heat sinks are capable of removing high fluxes of heat from small surfaces efficiently [1]. Although the heat removing capabilities of microchannel heat sinks are astonishing [2] yet they come with a catch of high pumping power requirements [3]. On the other hand, mini-channels requires small pumping power but their heat removing capabilities are not as brilliant as that of microchannel heat sinks. However, the issue could be addressed by using different heat transfer enhancement techniques. Various heat transfer enhancement techniques have been adopted in the literature i.e. using wavy channels [4], increasing surface roughness [5], small cavities on the surface of channels walls [6], applying magnetic fields [7–10] modifying shape of the channel [11] and changing the thermal conductivity of the coolant using nanofluids [12,13]. Heat transfer enhancement using nanofluids has drawn the substantial attention to research in last decade based on its ability to enhance thermal performance with only a small increase in pressure coefficient. A brief review of heat transfer enhancement in mini-channel heat sinks using nanofluids is as follows.

Wang et al. [14] optimize microchannel heatsink geometry for nanofluids inlet volume flow rate, pumping power and pressure drop across the heat sink. Moraveji et al. [15] Investigated effects of nanofluids on convective heat transfer coefficient in a mini-channel heat sink at different Reynolds numbers and volume fractions of nanoparticles (TiO_2 and SiC). They used a fixed configuration of mini-channel and showed that heat transfer coefficient in mini-channels increases with the increase in volume fraction of nanoparticles and fluid's Reynolds number. Peyghambarzadeh et al. [16] performed an experimental study to determine the heat transfer characteristics of microchannel heatsink using water-based CuO and Al_2O_3 nanofluids. They reported that 27% and 49% enhancement in the heat transfer coefficient could be achieved using 0.2% volume fraction of CuO and 1% volume fraction of Al_2O_3 respectively. Afrand [17] investigated the effect of nanoparticles (MgO) volume fraction (in the range of 0–0.6%) on the thermal conductivity of base fluid ethylene glycol. He showed

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Nomenclature

A	area [mm^2]
c_p	specific heat capacity [J $kg^{-1}K^{-1}$]
D_H	hydraulic diameter [mm]
H	height [mm]
h	heat transfer coefficient [W m^{-2} K^{-1}]
k	thermal conductivity [W m^{-1} K^{-1}]
l	length [mm]
LPM	liter per minute
MF	maldistribution factor
$\dot{m}$	mass flow rate [kg s^{-1}]
n	header shape parameter
N	total number of fins
Nu	Nusselt number
p	pressure [Pa]
pr	Prandtl number
Δp	pressure drop [Pa]
R_{th}	thermal resistance [K W^{-1}]
Re	Reynolds number
$\dot{q}$	flow rate [LPM
$\dot{Q}$	heat dissipated by coolant
$\dot{Q}_{cf}$	heat transfer rate through cell face
S_n	Surface normal [m]
s_f	fin spacing [mm]
T	temperature [K]
t_f	fin thickness [mm]
$\mathbf{u}$	velocity vector [ms^{-1}]
w	weight fraction
W	width of the header segment [mm]

Greek symbols

ϕ	volume fraction of nanoparticles
ϕ_{fl}	volume fraction of the base fluid
μ	dynamic viscosity [kg m^{-1} s^{-1}]
ρ	density [kg m^{-3}]

Sub and super scripts

ave	average
b	base plate
$drag$	drag
dr	drift
eff	effective
f	fin
fl	base fluid
i	interface
in	inlet
l	local
m	mixture
nw	near wall
max	maximum value
out	outlet
p	particle
s	sink
sl	solid
w	wall

experimentally that thermal conductivity of the base fluid increases significantly by increasing the volume concentration of nanoparticles (MgO). He reported a maximum increase of 21.3% in the thermal conductivity values of base fluid corresponding the nanoparticle volume concentration of 0.6%. Napthon et al. [18] performed an experimental study to test the effects of nanoparticles (TiO_2) in a mini rectangular-fin heat sink. They studied the effect of Reynolds number, nanofluid's inlet temperature and supplied heat flux on the heat transfer characteristics of the mini-channel heat sink. They reported significant enhancement in the heat transfer coefficient with nanofluids in comparison with de-ionized water. While pressure drop with nanofluids and deionized water was found to be approximately the same. Performance of mini-channel heat sink with $Al_2O_3 - H_2O$ nanofluids were investigated by Ho et al. [19]. They have reported that the performance of mini-channel heat sinks with nanofluids depends on the particle fraction dispersed in water and flow rate of the nanofluids. Sohel et al. [20] performed experimental study to evaluate the performance of mini-channel heat sink using $Al_2O_3 - H_2O$ nanofluids with the volume fraction of 0.1% to 0.25%. They have shown that heat transfer coefficient could by enhanced by 18% along with decrease of 15.72% in thermal resistance that brings down the base temperature about 2.7 °C. Azizi et al. [21] reported based on their experimental study that 17%, 19% and 23% enhancement in Nusselt number can be achieved using nanofluids with 0.05, 0.1 and 0.3% weight concentration of water base Cu nanofluids respectively. A numerical study was conducted by Ghasemi et al. [22] to compute the performance of a mini-channel heat sink with triangular shapes using $Al_2O_3 - H_2O$ nanofluids. They concluded that thermal performance of mini-channel heat sinks could be improved significantly using nanofluids as a coolant in comparison to deionized water without any significant sacrifice of pressure drop across the heat sink. Zhang et al. [23] performed an experimental study to investigate the effect of nanofluids and micro fin structure on the thermal and hydraulic performance of a mini-channel heat sink. They have shown that the use of $TiO_2 - H_2O$ nanofluids in mini-channel heat sink increased the heat transfer coefficient but increased the pressure drop as well. In an experimental study to evaluate the thermal performance of a mini-channel heat sink with $Al_2O_3 - H_2O$ nanofluid as a coolant, Ho et al. [24] showed that average heat transfer effectiveness could be enhanced in heating and cooling section by 3.5–22% and 9.5 to 62% respectively. Waqas et al. [25] conducted an experimental study to investigate thermal and hydraulic performance of a mini-channel heat sink using $TiO_2 - H_2O$ nanofluid. They concluded that Nusselt number is not affected by the heat power in the case of distilled water as a coolant. On the other hand $TiO_2 - H_2O$ nanofluid performed better at lower heating powers. They achieved a maximum enhancement of 12.75% with nanofluid in comparison with distilled water corresponding to lowest heating power.

Current study was conducted to evaluate the thermal and hydraulic performance of mini-channel heat sinks using nanofluid $Al_2O_3 - H_2O$ with different volume fraction i.e. 0% (distilled water), 1.0% and 2.5%. Effects of the channel configuration, the volume concentration of nanofluid and flow rate of coolant on the thermal performance of the mini-channel heatsink have been studied and reported using both numerical and experimental techniques. Moreover, the effect of all above-mentioned parameters on the hydraulic performance (pressure drop across the heat sink) has been computed numerically. Numerical computations were carried out using single-phase and two-phase mixture model. Results from the both single-phase and two-phase mixture model have been compared with experimental results and discussed. To author's best knowledge no other study in literature is available that involves the effect of channel configuration on the heat transfer enhancement capability of nanofluid in the mini-channel heatsink.

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