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ScienceDirect

Procedia Engineering 127 (2015) 110 – 117

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Computational Heat and Mass Transfer-2015

Thermal Performance Analysis of Jet Impingement with Effusion Scheme

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Abstract

The present work investigates the thermal performance of a copper-based coupled impingement-effusion heat sink. A three-dimensional numerical analysis was executed for steady state, incompressible laminar, flow and conjugate heat transfer. A constant heat flux of 100 W/cm^2 was applied at the base of copper substrate while on the other side a heat sink model was designed. The jet plate consists of multiple impingement jet nozzles and each jet nozzle was surrounded by six effusion holes, computational domain was defined by applying symmetric boundary conditions. The effects of the design parameters such as jet diameter, effusion-hole diameter, stand-off and jet-to-effusionpitch were investigated. The analysis was carried out at a low Reynolds number of 200 to prevail laminar flow conditions. The maximum temperature rise, total pressure drop, area-averaged heat transfer coefficient, thermal resistance and pumping power were discussed with various design variables e.g., the ratio of the pitch-to-jet diameter, standoff-to-jet diameter and area ratio of jet-to-effusion hole. The design with higher standoff-to-jet diameter ratio offers lower overall thermal resistance while design with lower standoff-to-jet diameter ratios offer lower pressure drop penalty. Higher heat transfer was associated with lower pitch-to-jet diameter and higher standoff-to-jet diameter ratio. The functional relationship between the overall thermal resistance and the pumping power was studied, which presents the optimal front within the design space explored in the present study.
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Peer-review under responsibility of the organizing committee of ICCHMT – 2015

*Keywords:*Micro-scale Heat Transfer; Heat Sink; Jet Impingement; Effusion Holes; Thermal Resistance; Heat Transfer Coefficient

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Peer-review under responsibility of the organizing committee of ICCHMT – 2015
doi:10.1016/j.proeng.2015.11.433

Nomenclature

A_s	surface area of the substrate base, m^2
d	diameter, m
h	heat transfer coefficient, W m^{-2} K^{-1}
H	height of the channel, m
k	thermal conductivity, W $m^{-1}K^{-1}$
l	length, m
$\bar{n}$vector in normal direction	
Δp	pressure-drop, Pa
P	pumping power, W
Q	volumetric flow rate, m^3 s^{-1}
q	heat flux, W m^{-2}
Re	Reynolds number
Rth	thermal resistance, K W^{-1}
S	inter jet-effusion spacing, m
t	thickness, m
T, ΔT	temperature and temperature-rise respectively, K
V	velocity of fluid
Greek Symbols	
μ	dynamic viscosity, Kg s^{-1} m^{-1}
ρ	density, kg m^{-3}
Subscipts	
f	fluid
i	jet inlet
o	outlet
max	maximum value
a	area averaged value
s	substrate
t	total
w	solid wall
Abbreviations	
DIUF	de-ionized ultra-filtered

1. Introduction

With recent development of high density power electronic industry, researchers are discovering new cooling methods to avoid thermal fatigue failure of the electronics components. The conventional air cooling methods have reached their own limitations.Liquid jet impingement cooling is very efficient cooling technique used nowadays, owing to remove large heat flux effectively. Crossflow and interference having adverse effect in conventional design of having jet impingements alone, addition of effusion holes to jet impingement offers better designs to avoid the negative effects of crossflow and interference by extracting spent fluid through effusion holes shortly after the impingement on target surface. Two possible locations of effusion holes were suggested e.g., holes in the target surface, [1, 2, 7] and holes in the same plane (injection plate) as the jets [8, 9].

Earlier, Hollworth and Dagan [1] proposed a design of jet impingement along with transpiration of fluid through a vent hole on target surface. They conducted experiments for inline and staggered jet arrays with respect to vented holes and found that staggered jets yielded more average heat transfer than inline arrangement. Andrews et al. [2] conducted an experimental analysis of overall heat transfer coefficient for impingement/effusion cooling system. They used the same impingement geometry for two different holes size of 2.16 mm and 3.27 mm on effusion plate.

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