Energy Conversion and Management 243 (2021) 114415

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Experimental study on single-phase convective heat transfer of interlocking double-layer counterflow mini-channel heat sink

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ARTICLE INFO

Keywords:
Counterflow
Heat sink
Mini-channel
Heat transfer
Cooling
Interlocking

ABSTRACT

This study proposes an interlocking double-layer mini-channel heat sink that can realize counterflow in which the flow direction is opposite in the adjacent channel. The heat sink consists of two-channel layers and a header/plenum structure serving as a pre-flow path for counterflow into the channels. The novelty and significance of the current study are that the counterflow multi-channel heat sink was first experimentally implemented through the design of a new internal flow distribution structure. The test data are obtained from the experimental evaluation of the single-phase flow cooling performance of the heat sink. The heat transfer characteristics of the heat sink are analyzed by separating the change in the single channel heat transfer coefficient increased by the counterflow channel effect. The thermal resistance representing the overall cooling performance of the proposed heat sink shows a significantly small value of 10^{-4} K-m^2/W order, which indicates the heat transfer performance advantage of the new heat sink. The beneficial effect of counterflow is verified by comparing the heat transfer coefficient obtained from the proposed heat sink and the prediction using the previous correlation for unidirectional single-phase flow heat transfer coefficient. The measured heat transfer coefficients are much larger than the predicted values by all kinds of past correlations. The difference between the measured value and the predicted value is much greater at low flow conditions where the temperature gradient increases more significantly with the flow direction. It can be concluded that this indirectly implies the fact that temperature gradient mitigation by counterflow results in an additional heat transfer improvement that is unpredictable in the previous unidirectional flow correlations. A new correlation is proposed to predict the heat transfer coefficient affected by the counterflow. This study is the first to experimentally implement a counterflow heat sink, confirming the distinct advantage of improved cooling performance over conventional heatsinks. In addition, this study is meaningful in that it presents a performance prediction model that can be used in design for the practical application of counterflow heat sinks.

1. Introduction

With the rapid development of mini/microelectronics, research on cooling technology for such high heat dissipation devices has been actively conducted. Due to the current trend of miniaturization of electronic devices and the complexity of components integration, a large amount of heat flux may occur in a limited area, causing the rapid temperature to increase in the device. The failure to manage the temperature rise in the devices may lead to performance degradation and failure. Thus, the research aims to maximize the cooling performance in the unit volume for long-term use and device maintenance. Tuckerman and Pease's pioneering research on micro-channel heat sinks received much attention, suggesting the possibility of an excellent cooling performance by increasing the heat transfer area in a unit volume [1]. Its stability in device thermal management is also considered as an additional advantage for application in electronics cooling [2,3]. The microchannel can be classified into single-phase [4–9] and two-phase [9–21] cooling according to the occurrence of phase change in working fluids, each of which has the merit of being more stability in system maintenance and the merit of further enhancing heat transfer performance, respectively.

Despite these advantages, there are some drawbacks to applying the mini/microchannel cooling methodologies. The temperature of fluid flowing into the channel is increased along the flow direction, and it causes a temperature gradient. The surface temperature of the heat sink

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https://doi.org/10.1016/j.enconman.2021.114415
Received 28 March 2021; Accepted 12 June 2021
Available online 24 June 2021
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