액상 냉각 매니폴드 마이크로채널 히트싱크의 열성능 예측

이한솔*† · 김성진*
*한국과학기술원 기계공학과

Thermal Performance Prediction of Liquid-cooled Manifold Microchannel (MMC) Heat Sinks with Plate Fins

Hansol Lee*† and Sung Jin Kim*
* Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology

1. Introduction

In response to the global push to reduce carbon emissions, electrification has become a growing trend. However, the increased use of electronic devices, including solar cells, radio frequency (RF) power amplifiers, and power converters, has led to a severe problem of thermal management failure in recent years.[1~3] These devices are based on wide bandgap (WBG) semiconductors such as GaN and SiC, which are well-known for their superior characteristics of high electrical breakdown voltage and high electron charge densities. However, the full potential of these semiconductors is limited by thermal constraints.[4] Therefore, it is crucial to adopt viable cooling solutions for electronic devices to alleviate these thermal constraints and ensure optimal performance.

Researchers have shown increasing interest in 3-D manifold microchannel (MMC) heat sinks as a potential solution to address thermal failures in electronic devices.[5] However, predicting the thermal performance of MMC heat sinks has been challenging due to their complex flow characteristics including jet impingement and developing flow. Previous models have been limited in accuracy, as they only considered the heat transfer characteristic of developing flow and did not account for the significant heat transfer enhancement resulting from jet impingement in MMC heat sinks.[6] Therefore, in the present study, a new semi-analytical heat transfer model incorporating jet impingement and developing heat transfer characteristics is developed and experimentally validated.

2. Results and discussion

2.1 Semi-analytical Nusselt number correlation

A Nusselt number correlation of MMC heat sinks, representing mixed convection of jet impingement and developing flow, is expressed by the form

$$\overline{\mathrm{Nu}}_{avg}^{\,n} = \overline{\mathrm{Nu}}_{jet}^{\,n} + \overline{\mathrm{Nu}}_{ch}^{\,n}$$

where $\overline{\mathrm{Nu}}_{jet}^{\,n}$ is the Nusselt number of jet impingement heat transfer, and $\overline{\mathrm{Nu}}_{ch}^{\,n}$ is the Nusselt number of developing flow. By using the scale analysis, the final form of Nusselt number is expressed as follows.

$$\frac{\overline{\mathrm{Nu}}_{avg}}{\overline{\mathrm{Nu}}_{ch}} = \left[1 + C_1\left(\frac{\mathrm{Re}_{jet}^{0.5}}{\mathrm{Re}_{ch}^{0.5}}\right)^n\right]^{1/n}$$

A parametric study on MMC heat sinks with different channel aspect ratios (AR) is conducted to obtain the undetermined coefficients. As a result, the obtained Nusselt number correlation shows good agreement with numerical data within 15 %.

2.2 Comparison to the current experimental results

The total thermal resistance of MMC heat sinks is predicted by effectiveness-NTU approach with the newly proposed Nusselt number correlation. The prediction results are compared with the current experimental results. The result shows that current model successfully predicts the total thermal resistance of the MMC heat sink with AR= 0.5 within 10%. On the other hand, the previous models based on developing flow heat transfer characteristic underpredict the total thermal resistance of the MMC heat sink up to 60% with respect to experimental data. This result implies that incorporating jet impingement in the heat transfer model for MMC heat sinks is necessary for the accurate thermal performance prediction.

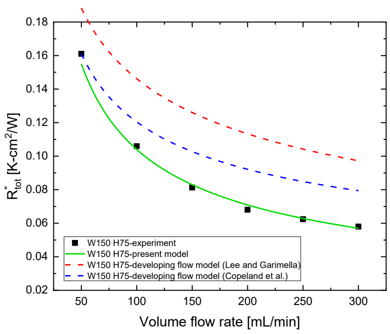

Figure 1 The total thermal resistance of the MMC heat sink with AR = 0.5 depending on volume flow rates.

† Presenting Author, numbers2x@kaist.ac.kr

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