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1-D two-phase flow analysis for interlocking double layer counter flow mini-channel heat sink

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ABSTRACT

Mini and micro-channel heat sinks with two-phase flow boiling are considered as one of the promising cooling methods due to their ability to efficiently manage high heat flux heat dissipation. However, it is characterized by a significant decrease in the heat transfer coefficient of the liquid deficient portion where the quality of flow is increased by the boiling in the channel. The heat transfer coefficient at which the wall dry-out occurs sharply decreases, which can cause a large temperature gradient in the direction of flow. Such a dry-out condition may correspond to the critical heat flux state, and a drastic decrease in cooling performance is inevitable. To alleviate the temperature gradient increase and to improve the cooling performance, the two-phase counter flow mini-channel heat sink with interlocking double layer structure has been proposed. The proposed mini-channel heat sink was designed based on the commercial IGBT module size and numerically analyzed by applying 1-D two-phase flow in each counter flow direction. Two-phase boiling heat transfer correlation and momentum equation were solved to calculate the pressure drop and analyze the cooling performance benefits of proposed counter flow heat sink. The applied analysis method was extended to the single-phase counter flow situation and the results were compared with two-phase flow case. From the results of the analysis, it was confirmed that the counter flow heat sink can obtain a more uniform temperature distribution than the conventional unidirectional heat sink. The non-uniformity of the temperature distribution due to the uneven flow rate of the parallel channels can be improved by applying the counter flow configuration.

1. Introduction

In recent years, studies on the cooling of high heat dissipation devices have been actively carried out. Research trends to maximize the cooling performance in the unit volume of the cooling system are also being observed simultaneously to improve the cooling efficiency. These research efforts are aimed at responding to the miniaturization and complexity of electronic devices that perform various functions in a convergent manner, reflecting recent trends in technology. The high performance and miniaturization of electronic devices can generate a large amount of heat flux from a small area and can rapidly increase the temperature of the device. Thus, if the heat release is not properly managed, the performance of the electronic device may be adversely affected. From this perspective, the two-phase cooling has the advantage that it can absorb more heat through latent heat by phase change as well as sensible heat change, as compared to single-phase cooling. Therefore, studies on two-phase cooling systems have been performed with various technology approaches such as jet impingement [1–4], spray cooling [5–7], and microchannel heat sink [8–11]. Of these technologies, mini/micro-channel heat sinks, especially channel cooling by two-phase flow, have received even greater attention due to the advantages of improved cooling performance by large heat transfer area, stability for maintenance, and ease of fabrication [12,13].

Numerous studies have been performed in the past to predict two-phase heat transfer coefficient changes in mini/micro-channels and many empirical correlations have been developed for a wide range of fluid types, operating conditions, and channel geometries. Gungor and Winterton [14] proposed a flow boiling heat transfer coefficient correlation based on approximately 3700 data points obtained from mini to macro channel sizes (d_h >> 1 -mm) including various fluids such as water, refrigerants, and ethylene glycol. This correlation was also modified to fit into the subcooled boiling range [15]. Tran et al. [16] investigated boiling heat transfer coefficient of R12 in a small circular channel (d_h = 2.46 mm) and rectangular channel (d_h = 2.40 mm) and proposed the correlation of boiling heat transfer coefficient within a nucleate boiling dominant region. Lee and Mudawar [17] also

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