Boiling Heat Transfer Characteristics and Enhancement in Layered Parallel Microchannels

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論文内容要約

This dissertation focused on the investigation of boiling heat transfer enhancement in a structure with layered parallel microchannels. Elucidation of boiling heat transfer mechanism in a structure with layered parallel microchannels to enhance local heat transfer for high integration of electronic devices such as semiconductors has become an important issue, and from the viewpoint of heat transfer engineering, including the robustness evaluation is required. In the structure with layered parallel microchannels, multiple parallel microchannels were arranged in layers to effectively use the limited three-dimensional space for cooling. The overall goal of this dissertation was to investigate boiling flow phenomena and to enhance boiling heat transfer in structures with layered parallel microchannels. This goal contributes to the progress of boiling heat transfer studies and the development of the electronic devices which are required to dissipate a high heat flux maintaining a low temperature of themselves. In this study, observation and measurement of boiling flows were conducted to confirm what kind of behavior of boiling heat transfer phenomenon occurred in the microchannels of the heat sinks. This dissertation summarized the results of this study and consists of 8 chapters.

In Chapter 1, the general introduction and background of this study were explained. The thermal problems in the industrial and academic fields were introduced and the motivation of this study was described. In the industrial field, the dissipation of the high heat flux maintaining a low temperature difference between a heat source and refrigerant is required. In addition, this requirement should be realized in a limited space using an available refrigerant. In the academic field, although the application of boiling heat transfer in a microchannel is significantly useful, the mechanism of heat transfer enhancement using a structure with microchannels has not been fully clarified. Therefore, it is important to understand boiling flow phenomena when applying boiling heat transfer in a microchannel.

In Chapter 2, the novel calculation method for heat sinks proposed in this study was introduced. In the numerical model, the heat transfer rate is estimated considering heat conduction of substrate material of heat sink block and boiling heat transfer in each microchannel using the one-dimensional homogeneous flow model. This novel calculation method is important to evaluate and design heat sinks proposed in this study. Furthermore, this model enables us to predict the boiling state such as vapor quality, mass flow rate and heat transfer rate in each layer microchannel. It also contributes to understanding boiling heat transfer in proposed heat sinks.

In Chapter 3, the heat transfer performance in the heat sink with layered parallel microchannels of uniform diameter was evaluated. A series of experiments was performed assuming an actual cooling system, in which a property of refrigerant was required to have anti-freezing. Therefore, a fluorochemical of HFC-245fa was used as a refrigerant and the heat sink was installed in a closed flow loop system. In the proposed heat sink, the size of the heat sink block was determined to be 25.4 mm in length, 25.4 mm in width and 3 mm in height, and 31 parallel microchannels of 0.5 mm in diameter were arranged in 3 layers in the heat sink block. In this dissertation, this heat sink was called “UNI-MC”. The effect of extending heat transfer surface area on the heat transfer performance was confirmed. In addition, from the experimental results, the effect of the thermal resistance between each layer microchannel was presumed. The wall temperature of the microchannel decreased as the distance from the heat source increased, and the boiling in microchannels at the far layer from the heat source was suppressed, and the flow resistance in these microchannels decreased. As a consequence, the mass flow rate in the microchannels in the layer near the heat source decreased, and the deterioration of flow balance led to a decrease in the heat transfer performance. Deep evaluation of this effect is important to understand the heat transfer potential of proposed heat sinks.

In Chapter 4, the heat transfer performance in the heat sink with layered parallel microchannels of different diameters was evaluated. As in the evaluation of the UNI-MC described in Chapter 3, HFC-245fa was used as a refrigerant, and the heat sink was installed in the closed experimental flow loop system. In the proposed heat sink, 31 parallel microchannels were arranged in 5 layers in the heat sink block of the same size as the UNI-MC; the diameter of the 1st layer microchannels was 0.5 mm in diameter, the same as the UNI-MC described in Chapte3; the diameters of the 2nd and subsequent layer microchannels were reduced as the distance from the heat source increased. The decrement rate was determined to be simply a constant value of 0.05 mm to confirm the effect of reducing the microchannel diameters. In this dissertation, this heat sink was called “DIF-MC”. The heat transfer performance of the DIF-MC was superior to that of the UNI-MC owing to improving the deterioration of the flow balance between each layer microchannel. By reducing the microchannel diameters, the mass flow rate in each layer microchannel increased in the order from the 1st to 5th layer microchannel. From these results, the effect of the thermal resistance between each layer microchannel presumed in Chapter 3 was indirectly substantiated.

In Chapter 5, the boiling phenomena in the two types of heat sinks were evaluated by visualizing experiments. To eliminate the effect of pressure in the experimental flow loop system on boiling heat transfer phenomena, the heat sinks were installed in an open flow loop system and degassed purified water was used as a refrigerant. One of the heat sinks had 5 microchannels with a uniform cross-sectional size of 0.5 mm × 0.5 mm. The hydraulic diameter of the microchannel was determined to be the same as the diameter of the UNI-MC. In this dissertation, this heat sink was called “UNI-MCv”. The other also had 5 microchannels, in which the cross-sectional size of the 1st layer microchannel was 0.5 mm × 0.5 mm, the same as the

UNI-MCv, that of the 2nd and subsequent layer microchannels were reduced as the distance from the heat source increased. In this dissertation, which were designed to be the same vapor quality using the calculation method described in Chapter 2, the heat sink was called “DIF-MCv”. The heat transfer performance of the DIF-MCv was superior to that of the UNI-MCv. In the UNI-MCv, the boiling in the microchannels was confirmed in only the layers near the heat source. Besides, in the DIF-MCv, the boiling in the microchannels was confirmed in all layers. This was caused by improving the deterioration of the flow balance between each layer microchannel owing to reducing the microchannel size as the distance from the heat source increased. From these results, the effect of the thermal resistance between each layer microchannel presumed in Chapter 3 was phenomenologically substantiated. Furthermore, it was confirmed that backflows contribute to improving heat transfer performance. By the occurrence of backflows, the heat transfer with evaporation was occurred extensively due to the growth of vapor bubbles and led to improving heat transfer performance.

In Chapter 6, the boiling phenomena in the same types of heat sinks described in Chapter 5 were evaluated using the degassed purified water as a refrigerant, and the relationships between the heat transfer performance at the point where backflows occurred and the influencing factors were confirmed. The degree of influence was evaluated by multiple regression analysis. The three influencing factors were decided to be the 1st layer microchannel size, the ratio of reducing microchannel size, and the length of the microchannel. The specifications of experimental specimens combined with the three influencing factors were determined by the orthogonal array of L4. It was confirmed that the influencing factors affect the boiling state and the different types of backflow behaviors occur under different influencing factors.

In Chapter 7, the improvement of the heat transfer performance in the heat sink with layered parallel microchannels of different diameters was numerically attempted by adjusting the vapor quality at the exit of the microchannel using the calculation method for the heat sinks with layered parallel microchannels described in Chapter 2. It was confirmed that the boiling states in each layer microchannel are possible to control by adjusting the microchannel diameters to be under a certain flow balance between each layer microchannel and the structure with layered parallel microchannels of different diameters has high robustness of the heat transfer performance against the dimensional variation of the 2nd and subsequent layer microchannels.

In Chapter 8, the conclusion obtained from each chapter are summarized. In this dissertation, the overall objectives described in Chapter 1 are achieved in each chapter.

This study concluded that the variation of the boiling flow phenomena, such as how to flow into other microchannel and the occurrence of backflow in multiple microchannels, due to the thermal resistance between each layer microchannel in the structure with layered parallel microchannels was confirmed, and it became possible to control the boiling flow phenomena in each layer microchannel; the reduction of the microchannel diameter in the second and subsequent layers as the distance from the heat source increase can contribute to improving the heat transfer performance; furthermore, from the visualizing experiments, the various backflow behaviors were confirmed and it was also confirmed that the backflows can be possible to enhance the heat transfer performance. In this study, the understanding of the boiling heat transfer phenomena in structure with layered parallel microchannels was advanced, and the possibility to enhance the boiling heat transfer performance by the application of structures with layered parallel microchannels was confirmed.

The author hopes that fundamental studies and applications described in this dissertation will contribute to further the development of heat and mass transfer studies on boiling heat transfer and its applications.