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Convective boiling in a parallel microchannel heat sink with a diverging cross section and artificial nucleation sites

Chun Ting Lu [a,*], Chin Pan [a,b]

[a] Department of Engineering and System Science, National Tsing Hua University, Hsinchu 30013, Taiwan, ROC
[b] Institute of Nuclear Engineering and Science, National Tsing Hua University, Hsinchu 30013, Taiwan, ROC

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ABSTRACT

To develop a highly stable microchannel heat sink for boiling heat transfer, three types of diverging microchannels (Type 1, Type 2 and Type 3) were designed to experimentally investigate the effect of different distributions of artificial nucleation sites (ANS) on the enhancement of flow boiling heat transfer, in 10 parallel diverging microchannels with a mean hydraulic diameter of 120 μm. Water was used as the working fluid with mass flux, based on the mean cross section area, ranging from 99 to 297 kg/m^2 s. The Type-1 system did not contain any ANS; the Type-2 system contained ANS distributed uniformly along the downstream half of the channel; and the Type-3 system contained ANS distributed uniformly along the entire channel. The ANS are laser-etched pits on the bottom wall of the channel and have a mouth diameter of approximately 20–22 μm, as indicted by the heterogeneous nucleation theory. The results of the present study reveal that the presence of ANS for flow boiling in parallel diverging microchannels significantly reduces the wall superheat and enhances the boiling heat transfer performance. The Type-3 system shows the best boiling heat transfer performance.

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1. Introduction

Flow boiling in microchannels has great potential to help overcome thermal problems in next generation electronic components [1] because it offers the advantages of highest heat fluxes, lowest pumping powers, and the highest efficiency compared to other advanced cooling technologies [2]. In the last few decades, flow boiling in microchannels has been extensively studied in terms of phase change phenomena and two-phase flow characteristics [3–11]. However, the problems of flow boiling instabilities [12] and the high wall superheat for flow boiling in microchannels are yet to be overcome [13,14].

Lee and Pan [15] indicated that the onset of nucleate boiling (ONB) takes place at relatively high wall superheats because the bottom walls of microchannels made of silicon on insulator (SOI) wafers is relatively smooth. With a higher wall superheat for ONB, the nucleated bubble may rapidly expand in both the forward and backward directions and may result in large oscillation of the pressure and temperature of the system.

For flow boiling in microchannels, Zhang et al. [16] found that the lack of active nucleation sites (ANS) may result in the high wall superheat and the severe pressure oscillations. They showed that a significant decrease in the wall superheat and pressure oscillations can be obtained by fabricating ANS on the channel walls.

Kandlikar et al. [17] improved the stabilization of flow boiling in six parallel microchannels by using inlet restrictors and fabricating ANS. These ANS were drilled by a laser beam on the bottom walls of the channel and had a radius of 2.5–15 μm. Kandlikar et al. [17] also pointed out that flow boiling in parallel rectangular microchannels with ANS and inlet pressure restrictors can help eliminate the instabilities. Agostini et al. [9] also demonstrated the absence of two-phase flow instability during flow boiling by placing the inlet restrictors at the entrance of each in their system with 137 parallel microchannels.

Koşar et al. [18] showed that a maximum heat flux of 2500 kW/m^2 can be obtained at a mass flux of 302 kg/m^2 s for flow boiling of water in five parallel microchannels with a hydraulic diameter of 227 μm and reentrant cavities of 7.5 μm mounted on both the sidewalls. They reported a criterion for the transition between nucleate and convective boiling.

Kuo and Peles [19] compared the heat transfer performances of structured and plain surfaces for flow boiling of water in five parallel microchannels with a hydraulic diameter of 223 μm and reentrant cavities of 7.5 μm mounted on both the sidewalls. They showed that a maximum heat flux of 6430 kW/m^2 can be obtained at a mass flux of 303 kg/m^2 s in microchannels with a structured surface on both sidewalls. They also demonstrated that the structured surface significantly reduced the boiling inception and enhanced the critical heat flux.

Lu and Pan [20] first explored flow boiling in a single microchannel with a converging/diverging cross section. The mean

* Corresponding author. Tel.: +886 3 5715131x34320; fax: +886 3 5716526.
E-mail address: cpan@ess.nthu.edu.tw (C.T. Lu).

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