International Journal of Thermal Sciences 50 (2011) 2413–2421

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Experimental investigations of flow boiling heat transfer and pressure drop in straight and expanding microchannels – A comparative study

K. Balasubramanian [a,b], P.S. Lee [a,*], L.W. Jin [a], S.K. Chou [a], C.J. Teo [a], S. Gao [b]

[a] Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore
[b] Institute of Microelectronics, A*STAR (Agency for Science, Technology and Research), 11 Science Park Road, Science Park II, Singapore 117685, Singapore

ARTICLE INFO

Article history:
Received 17 May 2011
Received in revised form
6 July 2011
Accepted 7 July 2011
Available online 12 August 2011

Keywords:
Expanding microchannels
Flow boiling
Two-phase pressure drop
Heat transfer performance
Instability
Stabilizing effect

ABSTRACT

Flow boiling experiments were conducted in straight and expanding microchannels with similar dimensions and operating conditions. Deionized water was used as the coolant. The test vehicles were made from copper with a footprint area of 25 mm × 25 mm. Microchannels having nominal width of 300 μm and a nominal aspect ratio of 4 were formed by wire cut Electro Discharge Machining process. The measured surface roughness (Ra) was about 2.0 μm. To facilitate easier comparison with the straight microchannels and also to simplify the method of fabrication, the expanding channels were formed with the removal of fins at selected location from the straight microchannel design, instead of using a diverging channel. Tests were performed on both the microchannels over a range of mass fluxes, heat fluxes and an inlet temperature of 90 °C. It was observed that the two-phase pressure drop across the expanding microchannel heat sink was significantly lower as compared to its straight counterpart. The pressure drop and wall temperature fluctuations were seen reduced in the expanding microchannel heat sink. It was also noted that the expanding microchannel heat sink had a better heat transfer performance than the straight microchannel heat sink, under similar operating conditions. This phenomenon in expanding microchannel heat sink, which was observed in spite of it having a lower convective heat transfer area, is explained based on its improved flow boiling stability that reduces the pressure drop oscillations, temperature oscillations and hence partial dry out.

1. Introduction

Flow boiling instabilities are a cause for concern in microchannel heat sinks. Two-phase flow instabilities may arise when boiling occurs in conventional size channels and more so in a straight array of multiple micro/mini-channels. Rapid bubble growth pushes the liquid–vapor interface of the bubble to both the upstream and downstream ends, which leads to a reverse flow in the straight microchannels. This causes some of the straight microchannels to carry the excess flow, resulting in flow maldistribution, pressure drop oscillations, temperature oscillation etc. These undesired effects must be controlled or mitigated because they can induce mechanical vibrations in the system, degrade the heat transfer performances (premature dry out, CHF limitation) etc. Channels with increasing cross-sectional area are being explored to promote unidirectional growth of the vapor plugs and prevent reversed flow. The present study explores the flow boiling heat transfer performance and pressure drop characteristic of one such geometry and compares it with its straight counterpart.

2. Literature survey

Two-phase flow instability is a complex topic because several effects may occur simultaneously and play a role in a coupled way. What is typical for these geometries is the appearance of an intermittent dry out which produces a vapor recoil in the micro/mini-channel. Depending on the compressibility of the inlet zone of the channel, quasi-periodical pressure fluctuations are observed. These oscillations are due to the competition of the inertia or gravity effects and the vapor recoil pressure linked to the imposed heat flux on the wall [1].

Several measures had been undertaken to mitigate or minimize these instabilities [2–6]. Mukherjee and Kandlikar [7], based on their numerical study, proposed that channels with increasing

* Corresponding author. Tel.: +65 6516 4187; fax: +65 6779 1459.
E-mail addresses: karthikb@nus.edu.sg (K. Balasubramanian), mpelps@nus.edu.sg (P.S. Lee).

1290-0729/$ – see front matter
doi:10.1016/j.ijthermalsci.2011.07.007