Review on the Effect of Aspect Ratio on the Rectangular Microchannels

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***Abstract*—This paper reviews the effect of aspect ratio on the other parameters that affect the thermal performance of the rectangular microchannels. In this paper both single phase and two phase flow in the microchannels are considered but two phase flow is considered more as thermal performance with two phase flow is more compare to single phase flow. The aspect ratio was not get that much attention in past for microchannel studies but it is considering in few studies in recent year and that studies concluded that there is minima occur for parameters of the rectangular microchannels and that minima values vary with aspect ratio variation. It should be consider as it has great potential to be a deciding factor for manufacturing the effective high performance rectangular microchannels.**

***IndexTerms*—Microchannel, Aspect Ratio, Flow Boiling, Annular Flow Model, Two Phase Flow, Minima**

I. Introduction

Very Large Scale Integration (VLSI) on a microchip leads to very high heat flux generation which requires effective cooling system for reliable, long term operations [1]. Conventional cooling is difficult to apply at micro or macro level. So, as alternative microchannel heat sink emerges as best option for cooling VLSI microchip due to high heat transfer coefficient derived from large surface to volume ratio [2].

Microchannels are defined as the flow passages that have hydraulic diameters in the range of 10 to 200 µm [3]. Microchannels can be classified based on size, surface area to volume ratio and cross-section shape. The performance of microchannels is depended on various parameters. Most of them are studied in two phase flow phenomenon and heat transfer study. But the parameter- aspect ratio (width to depth ratio of microchannel) is quite unexplored which is getting attention in recent years.

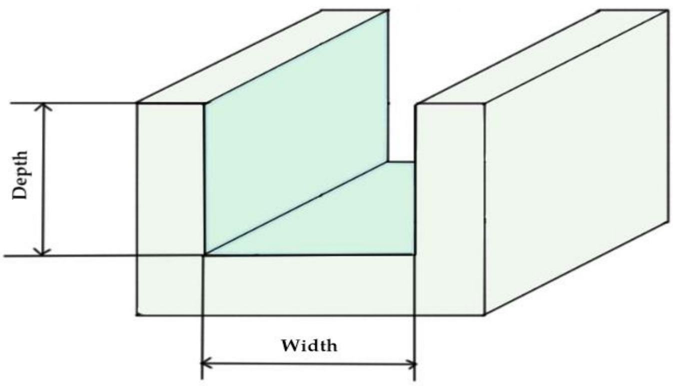

Figure 1 Schematic of Microchannel

The advantage of choosing rectangular cross-section channel is that comparison studies are easier, as there is only one aspect ratio value under consideration. (Note that multiple aspect ratio values exist for non-rectangular microchannels.) Aspect ratio does not only affect the performance of rectangular microchannels, but also aspect ratio itself affect other parameters of the rectangular microchannels. This paper reviews the effect of aspect ratio of rectangular microchannels to improve the possibilities of designing an effective rectangular microchannel heat sinks to tackle recent cooling issues in very large scale integration on microchips.

II. Literature Reviews

Tuckerman and Peace [4] introduced the concept of microchannel for the first time and they demonstrated the heat transfer characteristics of microchannel.

Review on Single Phase Flow in Microchannels

Afterward research has focused on modelling and optimization of single-phase liquid microchannel heat exchanger [5-6]. As the two phase flow heat transfer is more effective than the single phase flow heat transfer, focus was diverged to two phase flow based cooling schemes.

Review on Two Phase Flow in Microchannels

Yen et al. [7] demonstrated thetwo phase flow in 200 microchannelsand stated that heat transfer coefficient values was 25-75 $\mathrm{kW/m^2\,K}$ for two phase flow, which is 4-5 times larger than that reported for single phase flow in microchannels with similar dimensions. Yen et al. [7] also reported that for a square microchannel cross-section bubbly, slug and annular flow patterns were typically observed, and capillary flow pattern was rarely observed. Here, the dry out of the liquid film initiated at the center of the inner walls in an annular flow pattern. Many studies carried out to understand the heat transfer mechanism of two phase fluid flow in microchannels [7-13]. Jiang et al. [9] experimented two phase flow in triangular cross-sectional microchannel and observed that there was not observed any bubbly flow in either instance, but bubbly flow was observed in macrochannels. Zhang et al. [10] experimented two phase flow boiling in rectangular silicon microchannels with hydraulic diameters of 26 and 53 µm. They stated that there was only annular flow in microchannels. Hetsroni et al. [11] observed bubble growth in triangular silicon microchannels with hydraulic diameters of 103, 129 and 161 µm.Serizawa et al. [13] reported that two phase flow pattern varied in microchannel depending on the surface conditions of the inner wall of microchannel at a low velocities of vapor. Harirchian and Garimella [14] demonstrated the effect of channel width (100 to 5850 µm) on the flow boiling heat transfer of Fluorinert FC-77 for seven different silicon microchannel heat sinks for constant depth of 400 µm. They reported that for a fixed value of the wall heat flux, pressure drop increased with decreasing channel width.

Review on Aspect Ratio effect on Microchannels

The influence of cross-sectional aspect ratio on single phase fluid flow and heat transfer characteristics has been noted [15-20]. G. L. Morini et al. [17] and Peng and Peterson [18] studied theoretically and experimentally the pressure drop phenomenon in rectangular microchannels and stated that the product of friction factor and Reynolds number ($f.\mathrm{Re}$) showed a slight mono-tonic increase with aspect ratio.

S. G. Singh et al. [21] studied impact of aspect ratio on flow boiling of de-ionized water in rectangular microchannel, they reported that the pressure drop for two phase flow in rectangular microchannels experienced minima at an aspect ratio about 1.56 because of the opposing trends of frictional and acceleration pressure drops. C. W. Choi et al. [22] studied adiabatic two phase flow in rectangular microchannels with different aspect ratios with two phase flow consisted of water and nitrogen. They reported that the different aspect ratio can make different shapes of bubble and liquid at corner. As the aspect ratio of the rectangular microchannel decreased, the region of the bubble regime becomes wider and the liquid portion in the corner of the rectangular microchannel was reduced. U. Soupremanien et al. [24] studied influence of the aspect ratio on flow boiling in rectangular microchannels.They used two different single mini channels of same hydraulic diameter (1.4 mm).They studied with Forane 365HX and only two different aspect ratios (0.143 and 0.43). They reported that the effect of aspect ratio changed with the heat flux. Y. Wang et al. [25]studied flow boiling heat transfer of FC-72 with three different rectangular channels having the hydraulic diameters of 571, 762 and 1454 µm and aspect ratios of 20, 20 and 10, respectively. They reported that heat transfer coefficient increased with a decrease in the hydraulic diameter and partial dry-out had adverse impact on the heat transfer coefficient. Fu et al. [26] investigated the effect of aspect ratio on flow boiling heat transfer of HFE-7100 in diverging microchannel heat sinks (6 channels, D_h= 1.2 mm). Various values were chosen for the aspect ratio defined as depth to width ratio: 0.83, 0.99, 1.65, 2.47, 4.23 and 6.06. They reported that aspect ratio had a significant influence on the flow boiling heat transfer. Aspect ratio = 0.99 was the peak point for wall heat flux because of the liquid film thickness.S. Khandekar and M. Moharana [27] studied effect of aspect ratio of rectangular microchannel on the axial back conduction in its solid substrate. They stated that the aspect ratio strongly influences axial back conduction in the solid substrate.There exists a minimum in the average Nusselt number approximately near ε=2.0. B. Markal et al. [28] demonstrated the different aspect ratio of microchannel but kept hydraulic diameter constant.They obtain that heat transfer coefficient increases with an increase in the aspect ratio up to 3.54 and then decreases.

III. DISCUSSION

Pressure drop in flow boiling for different aspect ratios

Singh et al. [21] carried out an experiment for varying aspect ratios, 3 different heat flux values and 2 different mass flow rate values, with de-ionized water as the working fluid in silicon substrate made rectangular microchannel. (which was also fabricated by Singh et al. [21])In this experiment hydraulic diameter was constant 142±2 µm and also length was constant 20 mm.

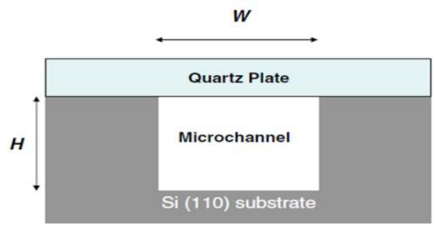

Figure 2 Fabricated rectangular microchannel [21]

The experiment carried out for heating power 0 and 3 W. The experimental results were shown as Fig. 3 which concluded that for given mass flow rate and heat flux value, the pressure drop first decreased with an increased in aspect ratio. And also the minimum pressure drop reported experimentally was at aspect ratio = 1.56.

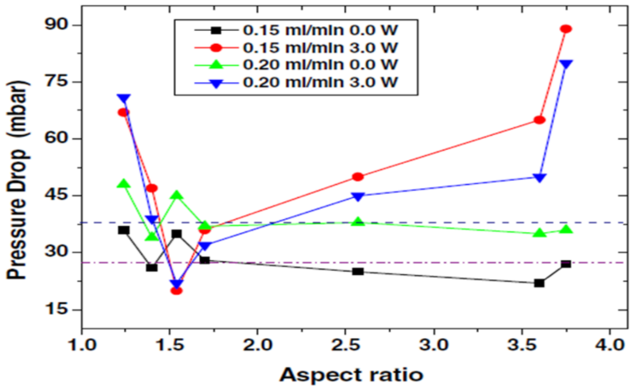

Figure 3 Experimentally determined pressure drop across the microchannel versus aspect ratio at a heat flux of 3W [21]

For the theoretical study they considered annular flow based model which is used to calculate the pressure drop through microchannels developed by Patankar [29]. The model follows Qu and Mudawar [30-31] was based on mass and momentum conservation for both liquid and vapor phases. The total pressure drop across the rectangular microchannel was sum of frictional pressure drop and acceleration pressure drop. Frictional pressure drop increases with aspect ratio due to a reduction in liquid film thickness and acceleration pressure drop reduces with increase in aspect ratio. These two opposite effects lead to a minimum in pressure drop with aspect ratio as shown in Fig. 4.

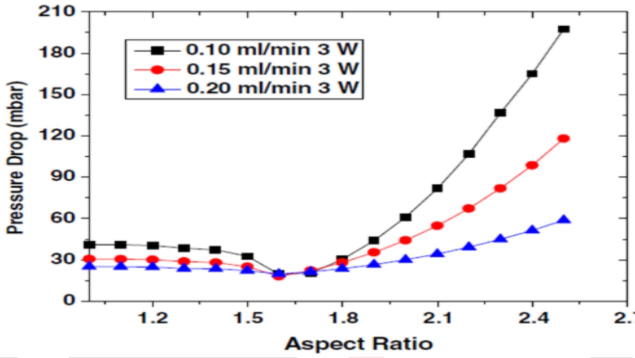

Figure 4 Theoretical results based on annular based model

Heat transfer coefficient in flow boiling in rectangular microchannel

B. Markal et al. [28] investigated effect of aspect ratio on heat transfer coefficient experimentally whose dimensions were as following:

No	Channel width (μm)	Channel depth (μm)	Aspect ratio	Hydraulic diameter (μm)
1	70	190	0.37	100
2	90	110	0.82	100
3	110	90	1.22	100
4	190	70	2.71	100
5	230	65	3.54	100
6	300	60	5.00	100

Figure 5 Geometric dimensions of microchannel

The experiment concluded that the heat transfer coefficient increase with an increase in the aspect ratio up to aspect ratio = 3.54 (especially for the transition from aspect ratio = 1.22 to 2.71), which is followed by a decrease for much higher values of aspect ratio.

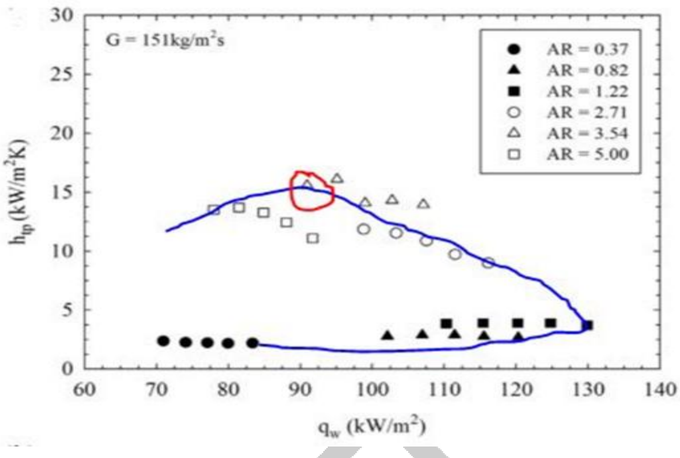

Figure 6Variation of heat transfer coefficient with wall heat flux at G=151 kg/m2

Flow patterns with different aspect ratio in rectangular microchannel

C. W. Choi et al. [22-23] experimented adiabatic two phase flow in rectangular microchannels with different aspect ratios of 0.92,0.67,0.47, and 0.16 and working fluid of liquid water and nitrogen gas. The experiments reported that pressure drop in a rectangular microchannel was highly related with the flow patterns which dependent on the aspect ratio.

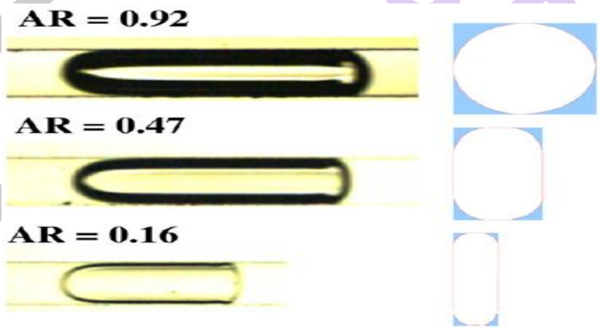

Figure 7Aspect ratio effect on bubble flow regime at Superficial velocity of liquid$j_L = 0.2$ m/s and Superficial velocity of vapor$j_G = 0.6$ m/s (Dark region = Thick liquid film thickness)

IV. Conclusion

Aspect ratio has significant effect on the rectangular microchannel thermal performance as it affects parameters pressure drop, heat transfer coefficient, flow pattern and this study bring attention to the point that there are minima exists that affect above mention parameters.

V. Future Scope

There are minima exists for different parameters while varying the aspect ratio for the microchannels but that further investigation need to be made to establish such minima for different fluids, heat fluxes and channel cross-section geometries. Further study in this area may lead to comparison criteria for manufacturing most favorable microchannel heat sink for particular application.

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