Convection and flow boiling heat transfer in a Mini channel Heat Sink

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Abstract:
With the trend towards increasing levels of integration in high density very large scale integral circuit and heat sink technology higher level of performance required to meet the elevated heat dissipation in electronic and optical devices. The distribution of two phase flow through the channels is often non uniform and in extreme cases there is almost no liquid flow through some channels which increase hot spot or dry-out problems. So for avoiding such problem uniform flow with breaking of the vapour bubble is needed. Here the heat sink geometry is such that the flow continuously get merged and diverged. Because of that the bubble get divided continuously and so uniform vapour liquid flow present. According to constructal law for a flow system to persist in time (to survive) it must evolve in such a way that it provides easier and easier access to the currents that flow through it. On this principle this model is based. In this paper the detailed review of the experiment of boiling heat transfer through mini channel heat sink is given.
The model is developed in CAD and generated with CNC end mill the channel size is 1mm x1mm x4 mm. And the constructal 3 loops are used here. The heat exchanger dimensions are 30mm x 30 mm. The temperature and pressure measurement is done with thermocouples intruded in the heat exchanger assembly. Maximum mass flux varied from 25- 400 kg/m2-s, the inlet pressure used is 0.15 Mpa which is obtained with the help of gravity driven system. The flow is laminar. The inlet fluid sends to be preheated up to 70o c. The experimental investigation of flow boiling in the mini channel heat sink is conducted with water as well as refrigerant as working fluid. For heat source plate type heater is used in contact with heat sink with heat flux ranges from 50- 500 kw/m2
Qualitative results are obtained from the experimental setup with the help of video and images with high resolution camera and for quantitative the process is continuing the qualitatively it shows that the better mixing of phases during boiling gives better heat transfer and no dry out problems present. Also there is no chance of bubble elongation so it will help to increase the capacity of the processor. Its exact values are not calculated but approximately the max temperature is 115o c. This model is different with the conventional straight channel so its advantages over that is better heat capacity but additional penalty here is that the pressure drop in this case is more than conventional one because of the junction losses is additional here, So more pumping power required.

1. INTRODUCTION:

The ever-growing demand for functionality and performance in microprocessors causes continuous increases in the number of transistors integrated per chip and the operating frequency and decreases in feature size. As a result, the total amount of heat generated and the heat flux have increased tremendously over the past decades and are predicted to so for many years to come. It is of vital importance to dissipate the heat from the active circuits to the environment while maintaining an acceptable junction temperature in order to maintain the reliability and performance of the devices.

Typically cooling of microprocessors is performed by attaching a heat sink with an integrated fan. To assess the effectiveness of the cooling solution the term thermal resistance is introduced. It is defined as the maximum temperature difference normalized by the total power dissipation. The temperature difference between the hot junction and the ambient air is usually used. It is generally agreed that air cooling technology is approaching its limit as the thermal management becomes increasingly demanding. As predicted by the ITRS roadmap the thermal resistance from the junction to ambient for high performance microprocessors has to be reduced from 0.46 oC/W for the year 2001 to 0.18 oC/W for the year 2010. On the other hand the available space for thermal management devices shrinks with the system size. Clearly, a shift from air cooling technology to liquid cooling technology is necessary to meet these challenges in the future.

1.1 Motivation

One of the promising liquid cooling techniques is to attach a mini/microchannel heat sink to, or directly fabricate mini/microchannel on, the inactive side of the chip. Usually in a closed-loop arrangement, coolant such as water is pumped through the microchannel to take away the heat generation.

In an early work by Tuckerman and Pease, a silicon microchannel heat sink containing parallel micro flow passages 50 μm wide and 302 μm deep was experimentally demonstrated to have a very low thermal resistance (as low as 9x10-6 K/(W/m2)). This resistance is substantially lower than that of conventional heat sinks. Since the minichannel heat sink is much smaller than an air cooled heat sink, the mechanical load on the chip is significantly reduced. However, several issues must be addressed in order to implement the minichannel cooling technique for the thermal management of electronics. Firstly the pressure drop due to flow friction in the microchannel is very large. For fully developed laminar flow, the Poiseuille number (the product of the friction factor and the Reynolds number) is constant. The pressure drop due to friction is thus determined by

$$\Delta P = 4f\frac{L}{d_H}\frac{\rho v^2}{2} = 2f\,\mathrm{Re}\frac{L}{d_H^2}v\mu$$

A constructive minichannel heat sink addresses this issue by increasing n, the number of channels while keeping Q constant. Constructive minichannel slightly increases the pressure drop. Results from a simple resistance network model.

Another issue associated with any single phase cooling technique, is the temperature non-uniformity in the chip being cooled. Along the flow direction, the coolant temperature rises as a result of the heat input. At the same time the heat transfer coefficients decrease along the flow direction due to the growing boundary layer thickness. In the entrance region heat transfer coefficient is extremely high due to the very thin local boundary layer [4]. It decreases asymptotically to the fully developed value if the channel is sufficiently long. Non uniformity in temperature is often undesirable for several reasons. Firstly, the spatial temperature gradient may adversely affect the performance and reliability of electronic devices.
Two-phase minichannel heat sinks are devices that feature flow boiling of a liquid coolant through parallel channels having a hydraulic diameter of 1000 μm. These devices are ideally suited for high-heat-flux dissipation from small surface areas in a broad range of emerging technologies. The combination of small flow passage area and flow boiling produce very high heat transfer coefficients with minimal flow rate and overall coolant inventory requirements, and provide better stream-wise temperature uniformity than single-phase micro-channel heat sinks. Deployment of two-phase micro-channel technology requires a comprehensive fundamental understanding of virtually all hydrodynamic and thermal aspects of phase change in small channels. The ability to accurately predict pressure drop and flow boiling heat transfer for a given micro-channel geometry and operating conditions is of paramount importance to both the design and performance assessment of a micro-channel heat sink. Because the interest in implementing these devices is fairly recent, brought about mostly by thermal management needs in computer and aerospace electronics, published studies on flow boiling in micro channels are quite limited. However, there is an abundance of studies on flow boiling in mini-channels, which were intended to aid in the design of compact heat exchangers. The hydraulic diameter for mini-channels is typically on the order of a few millimetres, which is several times larger than those found in micro-channel heat sinks. Nonetheless, the findings from mini-channel studies are useful at pointing out fundamental differences in flow boiling behaviour as hydraulic diameter is reduced from macro-scale (several centimetres) to the mini-channel scale, and progressively to microchannel

The studies clearly point to a departure in small channel boiling behaviour from that of macro channels, and cite appreciable deviations in predictions of popular microchannel heat transfer correlations from mini/microchannel data. For example, several studies point to a decreasing heat transfer coefficient with increasing vapour quality in the saturated flow boiling region, which is contradictory to macro-channel trends. Aside from general consensus over these deviations, the understanding of flow boiling in mini/micro-channels remains elusive. Furthermore, most mini/micro-channel studies use refrigerants as coolant, and the number of published studies using water is very limited. This is especially concerning since water is becoming the coolant of choice for many high-heat-flux cooling situations (e.g., lasers and fusion reactor blankets) because isothermal transport properties are far superior to those of all known refrigerants. This two-part study will explore the flow boiling heat transfer characteristics of water in mini/micro-channel heat sinks. The primary objectives of this study are to conduct a thorough experimental investigation of the heat transfer characteristics, assess the suitability of previous empirical correlations, and develop flow-pattern-based predictive tools for micro-channel heat sink design. In this Part I of the study, the findings from the experimental investigation are discussed, and fundamental differences from macro-channel results identified for single phase flow and heat transfer. This is followed by assessment of popular macro-channel correlations and five correlations specifically developed for mini/micro-channels, through comparison between correlation predictions and the present experimental data. In the part II of this study, same model is used to describe flow boiling in the saturated region of the mini-channel heat sink, which provides an alternative theoretical means to predicting the heat transfer coefficient.

1.2 Heat Sink

Currently, the most common cooling method used in industry is the use of heat sinks with various types of convection. Typically, force air is blown over the heat sink by using a fan, see figure

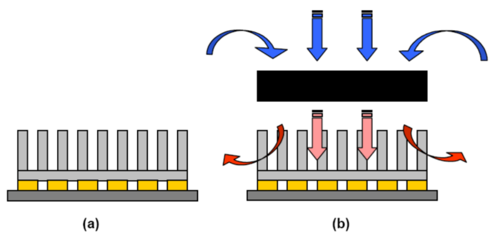

Figure 1.1 Air cooling heat sink

Conventional Heat Sinks

Methods	Typical height at heat input	Normal Load limit
1)Passive heat sink	10mm	5-50W
2)Semi-active Heat Sink	~10mm	15-25W
3)Active Heat Sink	35-80mm	10-160W
4) Liquid cooled cold plates	10-20mm	Huge
5)Phase change recalculating system	5-10mm	100-150W

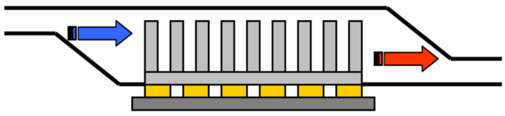

Figure 1.2 Fluid circulations through the heat sink

Heat sinks are commonly attached to the surface of the spreader to provide additional surface area for heat removal by convection. The convection may be natural air convection or forced air convection via a fan or duct. For very high power applications, it may be necessary to cool the chip directly with a heat pipe attachment, high-speed air jets, a direct heat sink attachment (cold plate), or dielectric liquid immersion.

1.2.1 Material Selection for Heat sink

The heat sink utilized in the MCM cooling system needs to be of high thermal conductivity, in order to aid the dissipation of an 800W MCM chip. Through the use of Cambridge Material Selector (CMS) program, a plot of thermal conductivity Vs density was created in order to narrow down the to the most effective materials for the design requirements. CMS yielded 6 out of 262 materials, which have high thermal conductivity and low density, see Table

Material	Density (Mg/m^3)	Thermal Conductivity (W/mK)
Brasses	8.8	220
Copper Berylliums	8.75	210
General purpose coppers	8.94	370
High Conductivity Coppers	8.94	390
Molybdenum, commercially pure grades	10.3	147
Molybdenum-Titanium Alloys	10.3	147

Heat sinks are widely used in electronics, and have become almost essential to modern central processing units. In common use, it is a metal object brought into contact with an electronic component's hot surface though in most cases, a thin thermal interface material mediates between the two surfaces. Microprocessors and power handling semiconductors are examples of electronics that need a heat sink to reduce their temperature through increased thermal mass and heat dissipation (primarily by conduction and convection and to a lesser extent by radiation). Heat sinks have become almost essential to modern integrated circuits like microprocessors, DSPs, GPUs, and more.

1.2.2 Construction and materials

A heat sink usually consists of a base with one or more flat surfaces and an array of
comb or fin-like protrusions to increase the heat sink's surface area contacting the air, and thus increasing the heat dissipation rate. While a heat sink is a static object, a fan often aids a heat sink by providing increased airflow over the heat sink thus maintaining a larger temperature gradient by replacing the warmed air more quickly than passive convection achieves alone this is known as a forced air system.

Heat sinks are made from a good thermal conductor such as copper or aluminium alloy. Copper (401 W/(m·K) at 300 K) is significantly more expensive than aluminium (237 W/(m·K) at 300 K) but is also roughly twice as efficient as a thermal conductor. Aluminium has the significant advantage that it can be easily formed by extrusion, thus making complex cross-sections possible. Aluminium is also much lighter than copper, offering less mechanical stress on delicate electronic components. Some heat sinks made from aluminium have a copper core as a trade off. The heat sink's contact surface (the base) must be flat and smooth to ensure the best thermal contact with the object needing cooling. Frequently a thermally conductive grease is used to ensure optimal thermal contact; such compounds often contain colloidal silver. Further, a clamping mechanism, screws, or thermal adhesive hold the heat sink tightly onto the component, but specifically without pressure that would crush the component.

1.3 Minichannel and microchannel

Many definitions of micro and mini channel hydraulic diameter are used throughout the literature. Kandlikar and Grande (2003) proposed the following classification:

- Conventional channels (*D*h > 3 mm),
- Mini channels (200 μm < *D*h < 3 mm),
- Micro channels (*D*h < 200 μm),

These definitions rely upon the molecular mean free path in a single-phase flow, surface tension effects and flow patterns in two-phase flow applications. The use of minichannel heat exchangers (hydraulic diameter about 1 mm) in compact heat exchangers improves heat transfer coefficients, and thermal efficiency while requiring a lower fluid mass. They are widely used in condensers for automobile air-conditioning and are now being used in evaporators, as well as in other applications such as domestic air-conditioning systems. However, more general use requires a better understanding of boiling heat transfer in confined spaces. In recent studies in mini channels the hydraulic diameter ranges from 100 μm to 2–3 mm. The channel cross sections were either circular or rectangular and much of the research concerned boiling. Commonly, classical correlations have been used with or without modifications to predict flow boiling results in mini channels. Microchannel heat sinks can be fabricated using the micromachining techniques that have been used for IC fabrication. This makes batch production possible and thus potentially reduces the fabrication cost.

2. CONCLUSION:

Direct liquid cooling has emerged as one of the most promising thermal management techniques for micro-systems where the control of both the operating temperature and the temperature cycling is still a challenging task. Here the minichannel heat sink was designed with square type of channel with different flow construct than conventional straight channels. So the points which were summarized from this experiment are

1. Liquid cooling here with low mass flow rate gives better results for single phase convection as well as boiling.

2. The pressure drop in this case is penalty because of the junction losses in the construct of channel. Here the results obtained are matching with the conventional channels. But this was not that much of loss because the advantage gained by the geometry is that due to merging and diverging of the flow the bubbles are not get confined there or elongated in the flow passage. So that the problem of occurring hot spot is removed completely.

3. Because of no bubble entrapment the cooling effect for the heat sink is uniform and also due to liquid in contact with the base the heat dissipation capacity is get increased so the power for processor could be achieved higher capacity.

4. Also the pressure used here were just above atmospheric for getting the driving effect only so the analysis shows better results that similar system can be designed for the close loop system of liquid cooling.

5. Results obtained here are tried to satisfy the predicted results but due to the system used having components with greater uncertainty, so because of that also the results obtained are not that much correct as predicted. So in future it will be
possible that to use a better measuring system equipments.

6. It is obtained that the critical heat flux case for the design here at 120oC of surface temperature for water as a cooling fluid which was reliable than the refrigerants.

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