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Experiment Study and Numerical analysis of (110) Silicon Base Microchannel Applying on Electronic Cooling

C. S. Yu*, J. S. Yu, S. W. Kang
Department of Mechanical and Electro-Mechanical Engineering, Tamkang University
151 Ying-Chuan Rd., Tamsui, 25137, Taiwan, R.O.C.
Tel: 886-2-26215656 Ext.2613; Fax: 886-2-26209745
892340067@s92.tku.edu.tw
jason.yu@advantech.com.tw

Abstract: Microchannel heat sink is fabricated on silicon wafer by anisotropic etching, and used Pyrex #7740 as a transparent cover which integrated by anode bonding. Rectangular microchannel presents the flow phenomena of fluid in micro scale, and this study focus on the boundary conditions which hydraulic diameter (D_h) is from 80mm to 530mm and Aspect ratio is from 0.24~7.8 of working fluid (DI water). While the size of microchannel is decreasing, laminar flow occurs on the low Reynolds number, which caused by the interaction of viscosity and friction on boundary layer. Sequentially, the influence of dimension decreasing on microchannel that induced transition and turbulent flow in early stage as Reynolds number is still in the range of 600~800. Pressure drop is high (2 bar) when fluid flows through the micro channel, and flux is constrained by the flow resistance during experiment operating. In this study, it takes effect by increasing aspect ratio to reduce pressure drop and enlarge the conductive surface. Geometry of microchannel, hydraulic diameter, and aspect ratio are the key factors in flow phenomena investigation. This research presents the difference between micro scale flow and traditional pipe flow by consideration of Reynolds number.

By using computer aided engineering to optimize the aspect ratio of microchannel, which can find the maximum conductive surface under the limitation of pressure drop. The best value of aspect ratio is 0.88~1.22. The simulation result makes good sequence with experiment data. Based on this methodology, numerical analysis can be used to design the optimal microchannel on wafer for cooling hot spot.

Key word: Microchannel, (110) Silicone, CAE, Heat transfer

1 Introduction

The increased electrical performance required by computer system and it caused microprocessor thermal. On the component level, the continued growth in thermal design power for high frequency application, and the attendant increase in equipment heat load. Obviously, thermal issue becomes very important on maintaining high reliability of advanced computer system. Micro channel heat sink embedded on (110) wafer, which not only includes heat source and heat sink without interface resistance, but also can eliminate hot spot on chipset. The investigation of micro channel flow includes micro machining, precise measurement, envelopment, and numerical analysis. New technology keep improving and developing with the demand of high performance system. The more complicate application is widely used, the more detail phenomena needed to verify by basic theorem and experiment in studying physical and chemical methodology. Pfahler measured friction in micro channel by using gas and fluid as working material [1] [2]. The constant of friction （C_f=f*Re）is lower than predicted data from theory, and the constant increasing as Reynolds number is lower. Friction constant becomes independent when Reynolds number is higher. Pfahler also found wall friction increased by higher aspect ratio of micro channel. That illustrated micro flow phenomena is different to common pipe flow no matter changing any different working fluid.

Choi used nitrogen to pass the micro channel which diameter is 3.0μm from 81.2μm. The result shows flow and heat transfer is different to convection pipe flow. The friction factor is lower than the data of traditional theory or calculated by formula. The same thing happened in laminar, transition, and turbulence [3].

Wand and Peng[4], Peng and Peterson[5], Peng et al. [6], studied heat transfer characteristic of force convection, and experiment result shows the laminar becomes transition from Re=300 to Re=400, and turbulence of fully develop flow is from Re=1000 to Re= 1500. These data acquisition are all experimental measurement.

In 1996, Choquette and Asako [7] focused on numerical analysis for optimal simulation, and the key factors of micro channel are aspect ration, Nusselt number, and friction factor. The model includes comparison with heat transfer and total system power by vary geometry, property of construction, and boundary condition. Based on these parameters to design optimal dimension of micro channel and fin efficiency. The result indicates there existed lower thermal resistance in laminar flow, then it can prevent highly pressure loss which caused by turbulence in micro channel. Therefore, micro channel heat sink can be embedded on electronic components by taken this advantage of lower power loss.

In 1998, T. M. Adams and S. I. Abdel-Khalik [8] used round micro channel which diameter is from 0.76mm to 1.09mm to compare the different phenomena of force convection flow with large pipe. Based the test result to revise the experiential formula of micro flow, and it can meet the flow mode of actual force convection behavior.

2 Formulation

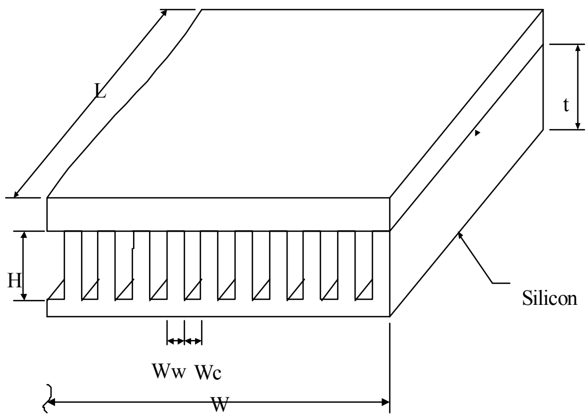

Fig1. Rectangular Microchannel Model

Micro channel heat sink can be embedded on processor with same wafer. The purpose is to eliminate thermal resistance between interfaces.

2.1 Geometry

That an important factor of MCHS is its geometry, and it influences friction magnitude in micro channel. The calculation of dimensionless analysis is according to actual size of micro channel.

$$R_e = \frac{\rho v D_h}{\upsilon} \qquad (1)$$

$$D_h = \frac{4A}{P} \qquad (2)$$

2.2 Pressure

Pressure is proportion to pipe length, and it is relative to pumping power. Theory of rectangular duct can be applied to calculate laminar flow as range of 0<Re<100 and Dh≧60μm. In order to follow the assumption of fully develop laminar flow when determines the length of ducts, it is necessary to prevent the influence in inlet section. Therefore, entrance length of laminar flow is calculated by the experiential formula of pipe flow.

The influence of entrance length can be ignorance, because it is 50 times to Le when Re =100 and D_h= 100μm.

$$Le = 0.06 \operatorname{Re} D_h \qquad (3)$$

$$f = \frac{8\tau_w}{\rho v^2} = \frac{2D_h \Delta p}{\rho v^2 L} \qquad (4)$$

$$f = \frac{C_f}{R_e} \qquad (5)$$

$$f = \frac{0.316}{R_e^{\ 0.25}} \qquad (6)$$

2.3 Working fluid

Viscosity of working fluid can suppress disturbance of laminar flow on boundary. It follows relative formula in traditional pipe flow by using water as working fluid as its width is 80μm. in a word, it physical properties. The proportion of pressure drop decreasing accompany with Reynolds number increasing. Error is only 3~5% between Experiment data and theorem data.

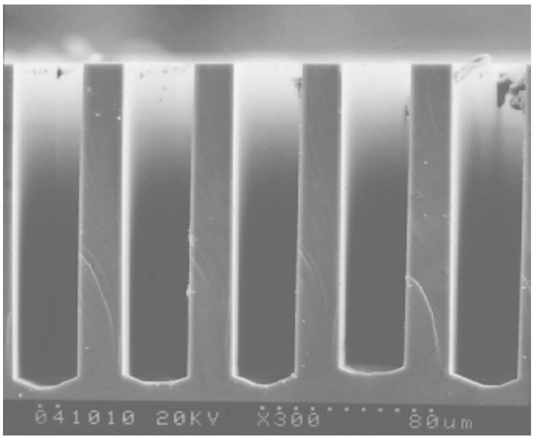

Fig.2 Silicon base microchannel

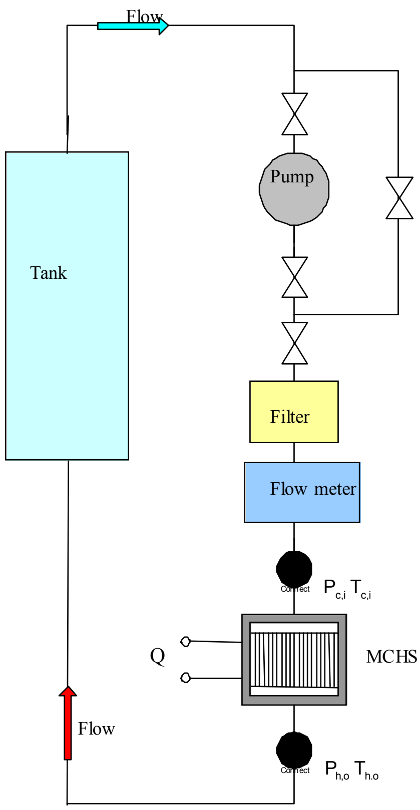

Fig.3 Experiment setup

3 Computer Aided Analysis

The system simulation of the entire 3D structure led to understanding the heat transfer phenomena of a microchannel heat sink. The research work involves the investigation of MCHS thermal solutions to a proposed 3D CAE design.

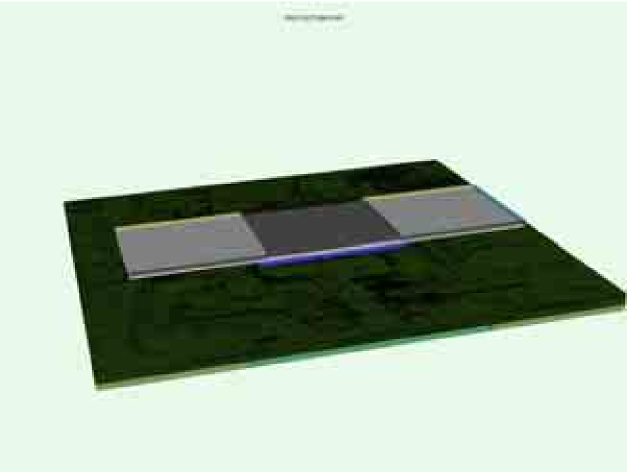

Fig.4 CAE model

3.1 Setup and Simulation

To simulate this design experiments which are performed with a FEM model.

Micro channel is a highly efficient heat transfer devices with a considerable potential for developing in micro scale. By rapidly computer science changing, thermal performance of cooling devices becomes extremely important. Cooling system such as liquid cooling embedded on micro channel need to be compact and effective in various applications, and this study shows better performance of MCHS than a heat sink or a heat pipe. We compare these experiment data with the results of CAE simulation model, and get good trend to this novel design. These results clearly indicate that the advantage achieved by virtue of heat transfer, which is dependent on experimental instrument and test equipment. First all of this study, we state the setups and procedure of experiment and CAE model. This study also illustrates the mathematical simulation of entire system.

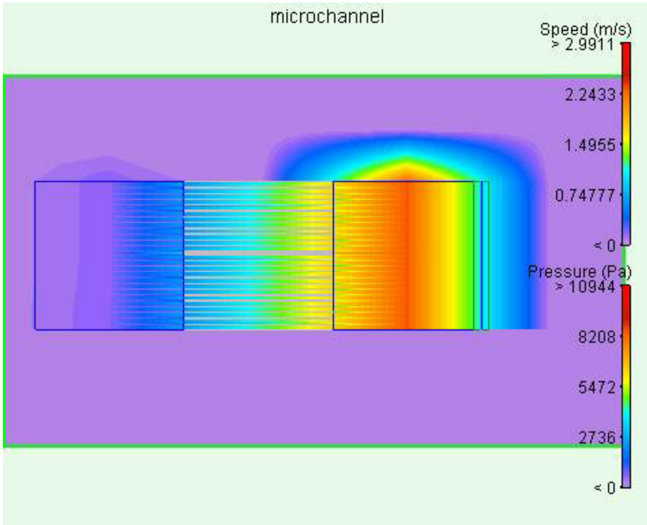

Fig.5 Temperature distribution on MCHS

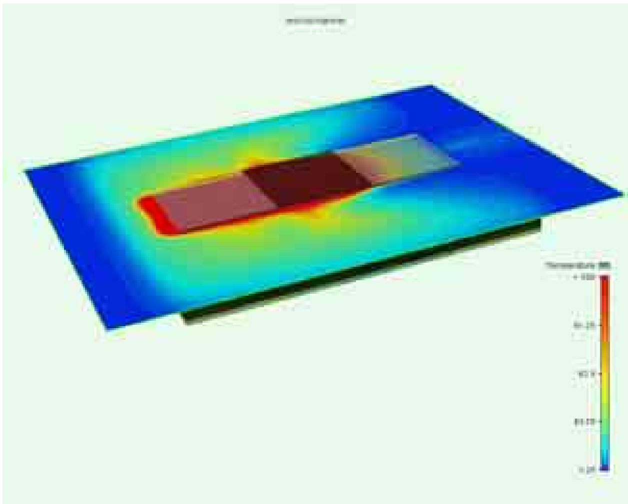

Fig.6 Temperature distribution on chip

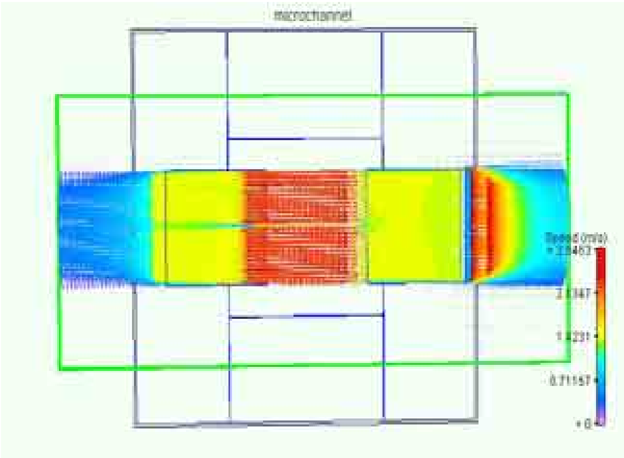

Fig.7 Velocity distribution on MCHS

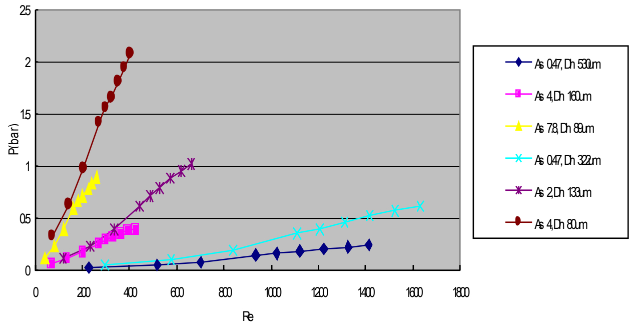

Fig.10 Pressure drop vs. Reynolds number

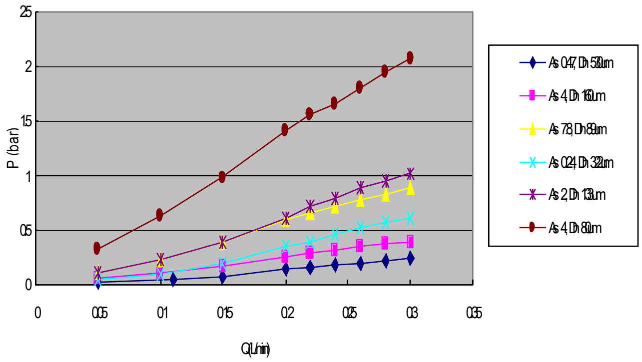

Fig.8 Pressure vs. flow rate

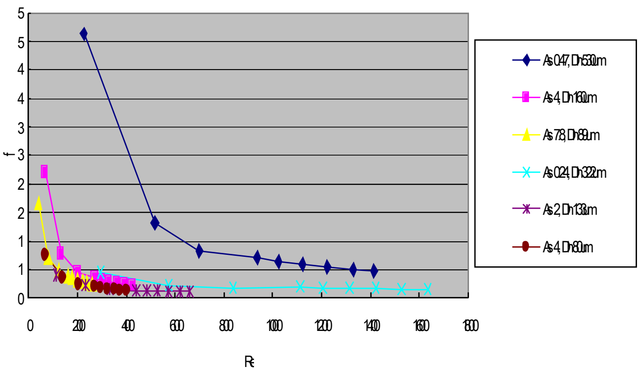

Fig.9 Friction factor vs. Reynolds number

4 Conclusion

The feature of this research is using a transparent #7740 glass as an observational window. We can record the operating phenomena in a microchannel heat sink, and compare with CAE simulation results and experimental data. According to this method to modify the model design and improve the thermal performance of a microchannel. Consequently, the experimental data indicate the operating situations of heat transfer and those parameters are consistent with CAE simulation results. In this study, It also provides a more efficient model, and show its highly thermal performance as a cooling device. By constructing the FEM model of a micro channel heat sink (MCHS) system to solve a detail module in advance, and the results get good trend to a real system. Although the CAE simulation exists numerical error (10%), It can be used to develop and predict the performance of a new design. The best value of aspect ratio is 0.88~1.22. The simulation result makes good sequence with experiment data.

To summarize those factors and get a good approximation to a preliminary research of this application field, and further improvement of diminishing model size and upgrading performance is under way.

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