Effect of Heat Transfer Performance and Thermodynamic Analysis of Complex Structured Double-layer Microchannels Heat Sink

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Abstract. As microelectronics become more and more integrated, in order to solve the increasingly serious microelectronic heat dissipation problem. Design of a complex structure with a double layer channel. The upper layer is a rectangular channel and the lower layer is a complex structure of the design. The DLCF (double layer counter flow) and SLCF (single layer counter flow) are compared numerically. The innovative design suggested in this paper is contrasted with the upper and lower layers, which are both rectangular channels. The simulation is carried out using FLUENT software. Based on previous studies, the concept of enhanced heat transfer coefficient was used to predict the heat transfer efficiency of channels. The friction factor, Reynolds number, as well as the temperature and thermal resistance along the channel are derived. From the results, it is clear that the complex structure of the double-layered channel designed in this paper has a higher heat transfer efficiency. The enhanced heat transfer factor number is higher.

Keywords: Microchannel Heat Sink, Enhanced heat transfer, Numerical simulation, Water cooling, Double Layer.

1. Introduction

Microelectronics technology has developed quickly in recent years due to the advancement of science and technology. With the development trend of large-scale integration technology and micro-miniaturization, the heat flow of these devices has increased and the heat dissipation power of micro-electronics is getting higher and higher. If the heat generated cannot be effectively reduced in time, the surface temperature of the components is reduced. It will cause the performance of the product to decline or even damage the components. Serious constraints on the military, science and technology, energy and biochemical development. The heat dissipation of microelectronic components is one of the most important concerns of the international community at present, where heat dissipation is an emergency problem to be solved. The double-layer hot channel is one of the most effective ways to dissipate heat and cooling.

Internationally different scholars have studied microchannels and focused on updating the size, structure and shape.

Vafai et al. [1] indicated the concept of a double-layer microchannel with higher heat dissipation efficiency and increased heat transfer performance compared to a single-layer microchannel with the same size and shape. The double microchannel heat sink reduces flow temperature differences more effectively. Tu-Chieh et al. [2] proposed that for the thermal performance of a double-layer microchannel heatsink with two layers of the same structure was superior to that of a single-layer heatsink by an average of 6.3%. Wu et al. [3] proposed that the speed of the upper microchannel in a double-layer heat sink structure could be adjusted to be lower than the speed of the bottom channel to refine the heat dissipation performance. Jeevan et al. [4] indicated that DLCF (double layer counter flow) thermal resistance is more lower than SLCF (single layer counter flow) thermal resistance.

At present, international experts and scholars on double-layer microchannel heat sinking mainly focus on the case where the two layers are structurally identical. However, the comparability is poor due to the differences in structure and dimensions. In summary, this paper provides a double layer with different structures of the heat sink and controls the velocity of the two layers with different structures, heat sink base thickness, rib height, rib width, rib spacing, and uses counter flow DLCF

based on previous research. A theoretical model is created using numerical simulation techniques, and the heat dissipation impact of this microchannel heat sink is evaluated. The efficiency of specific structures. This provides guidance on design optimization.

2. Theoretical analysis

For this paper the ANSYS FLUENT software we used. Assume that the cooling medium is an incompressible liquid and flows in the x direction with zero velocity in the y, z direction and is ignored thermal radiation. The flow process is also consistent with the Navier–Stokes equations. For mathematical model description equations depends on three equations.

$$\nabla \cdot U = 0 \tag{1}$$

$$\rho_f \left(U \cdot \nabla U \right) = -\nabla \mathrm{P} + \nabla \left(\mu_f \nabla U \right) \tag{2}$$

$$\rho_f c_p \left(U \cdot \nabla T_f \right) = \nabla \left(\lambda_f \nabla T_f \right) + \Phi \tag{3}$$

$$\lambda_s \nabla^2 T_s = 0 \tag{4}$$

Where U is fluid velocity;
ρ_f is density
P is pressure
μ_f is kinetic viscosity
c_p is heat capacity ratio
Φ is dissipation function
The physics property of the material of model and fluid as below:

Table 1. The Physics Property of Materials

Material	Density [5] (g/cm^3)	Specific Heat Capacity [6] (J/g K)	Heat Conductivity (W/m/K)
Si (Silicon)	2.329002	0.712	148
H_2O (Water)	0.997047	4.182	0.6

The Reynolds number is expressed in heat sink as [6].

$$Re = \frac{\rho u_{in} D_h}{\mu} \tag{5}$$

Where D_h is Hydraulic Diameter [m];
u_{in} is inlet velocity [m/s]
ρ is density of fluid [kg/m^3]
μ is dynamic viscosity [$N \cdot s/m^2$]
In the calculation, the calculated value of the friction factor f and Nusser number Nu can be calculated from this formula [7].

$$f = \frac{\sum_i^n \Delta P_i D_h}{2\rho L_{ch} u_\infty^2} \tag{6}$$

$$Nu = \frac{hD_h}{k} \tag{7}$$

$$Q = c_p \dot{m} \Delta (T_{out} - T_{in}) \tag{8}$$

$$h = \frac{Q}{NA(T_b - T_f)} \tag{9}$$

Where Q is Input heat [W];
N is number of channels
h is Heat transfer coefficient [$W/(m^2 \cdot K)$];
c_p is specific heat at constant pressure [$J/kg \cdot K$]

A is the contact area between fluid and solid [m^2]
T_b is the Average ground temperature [K]
$\dot{m}$ is mass flow rate [kg/s]

The heat transfer effect of the heat sink with enhanced heat transfer measures can be expressed in the filed of the enhanced heat transfer factor η [8]. The enhanced heat transfer factors due to the Nu/Nu_0 and f/f_0 are of comparable order of magnitude, indicating that heat transfer and flow friction are comparable and therefore This parameter is therefore more accurate for evaluating the overall heat transfer performance of the microchannel. Variation of the enhanced heat transfer factor with Reynolds number. The equation is as follows.

$$\eta = \frac{(Nu/Nu_0)}{(f/f_0)^{1/3}} \tag{10}$$

The subscript 0 indicates the value of the reference heat sink.

When defining thermal resistance, we will take the difference between the average temperature of the channel heating surface and the inlet temperature of the fluid and the ratio of the heat absorbed by the fluid as the total thermal resistance. The equation for thermal resistance is as follows [7].

$$R = R_{conv} + R_{cond} + R_{cap} \tag{11}$$

$$R_{conv} = \frac{(T_1 - T_0)}{Q} \tag{12}$$

$$R_{cond} = \frac{\delta}{hA} \tag{13}$$

$$R_{cap} = \frac{1}{2c_p\dot{m}} \tag{14}$$

Where δ is Equivalent thickness of the thermal conductive layer.
R is the thermal resistance.

3. Model description

3.1. Physical Model

In the design model, we have used silicon as the material for the channels. The cooling water flows into the microchannel heat sink in a unidirectional manner. Due to the large number of microchannels inside the heat sink, it would have been too demanding on the computer performance to use the complete channel for the simulation, so the model was reasonably simplified by selecting one microchannel and half the width of its adjacent ribs to build the calculation model and ensuring that the thickness of the model and the length along the cooling water flow direction were consistent with the actual model.

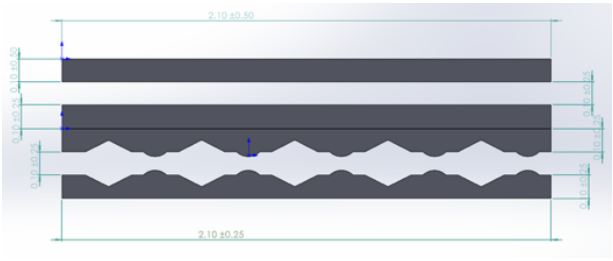


Figure 1. Diagram of heat sink

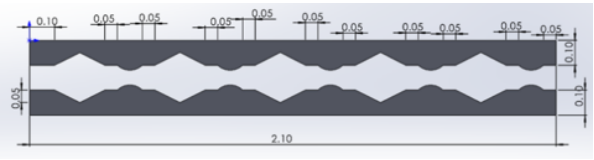


Figure 2. Diagram of Lower microchannel

Fig. 1 shows a diagram of a single heat sink microchannel with a specific structure consisting of ten parallel silicon-based microchannels with a total length of 21mm. 5mm rectangular areas are provided at the inlet and outlet at both ends of the channels so as to make the flow more uniform. Fig. 2 shows a diagram of the lower single microchannel with the parameters shown in the diagram.

3.2. Model Validation

In the setting model, we set the channel inlet velocity as u_0 and the temperature is 293 K. We set the energy on, the viscous model as SST k-omega. Because the outlet is connected by the Atmosphere so we set the Gauge Pressure at the outlet as 0. Assumption no backflow and slip in this channel.

The validation of the model is divided into the validation of the mesh independence and the validation of the numerical algorithm. Mesh independence validation is a test of the accuracy of a model by selecting different ranges of mesh numbers and examining the effect of changes in mesh numbers on the calculation results. We started with 3D modelling in Solid works and then used Ansys Mesh software for the meshing. When dividing the grid three different grid forms were divided. In the first type the grid is 85437, in the second 1518498 and in the third 2383139. in the first type most of the grid masses are concentrated below 0.75. In the second and third type most of the grids are concentrated above 0.75. After comparison we choose the second one with a grid number of 1518498. This not only ensures the accuracy of the results, but also shortens the calculation time.

In FEA calculations of mesh convergence, we can obtain convergence plots in Fluent. We can tell that the calculation has converged and the simulation is valid when the individual curves level off.

4. Result and discussion

Using the equations provided in the previous section we can obtain various relationships between Reynolds number, friction factor, temperature and enhanced heat transfer factor.

4.1. Thermodynamic Analysis

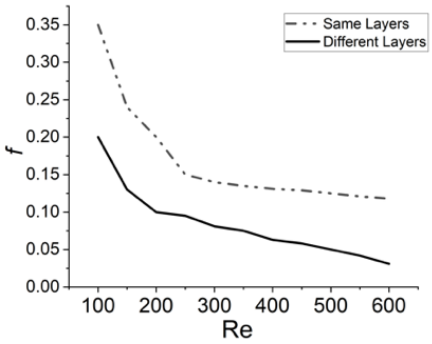


Figure 3. Ffriction factor and Reynolds number

As shown in Fig. 4, the friction factor is lower for the two different layers, which indicates that more heat is carried away.

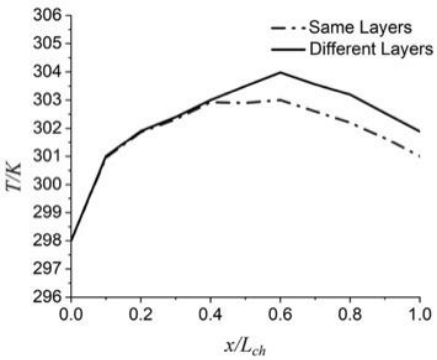


Figure 4. Temperature along the microchannel at the bottom (Re=233.3)

As shown in Fig. 5 and Fig. 6, the temperature gradually increases along the length of the heat sink channel, reaching a maximum at a certain point in the middle and then starting to decrease. Chai et al. [9] indicated the countercurrent temperature is characterized by the highest temperature point occurring in the microchannel middle area. This phenomenon is consistent with that described in the present paper. The temperature is lower in the two layers of the same structure than in the structure where the lower layer is a complex channel [10]. This means that less temperature is carried away. Therefore, the upper layer with a rectangular channel and the lower layer with a complex channel produce a more efficient heat exchange.

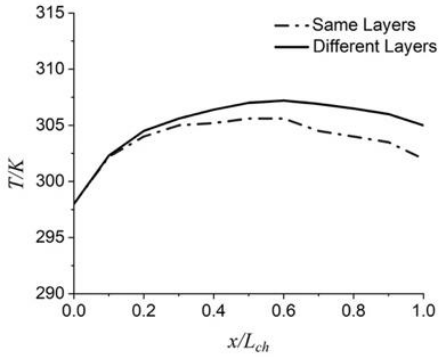


Figure 5. Temperature along the microchannel at the bottom (Re=100.6)

4.2. Thermal Resistance Analysis

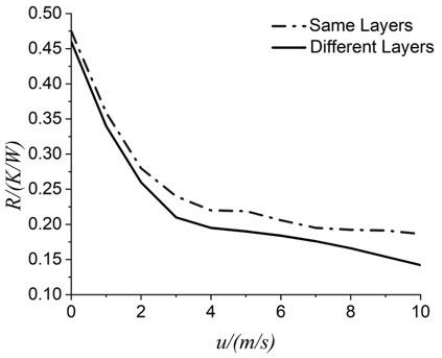


Figure 6. Thermal resistance and inlet velocity

Fig. 7 point out the variation of DLCF and SLCF thermal resistance with inlet velocity. We can observe that the DLCF has a lower thermal resistance, which is the same conclusion as in the paper [3]. In addition, the thermal resistance is reducing as the fluid inlet velocity rises. This indicates that we can improve the heat exchange by increasing the inflow velocity in order to decrease the thermal resistance.

4.3. Enhanced Heat Transfer Factor Analysis

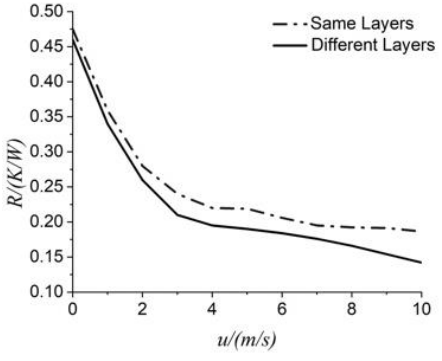


Figure 7. Enhanced heat transfer factor between inlet velocity

The relationship between the inlet velocity and the improved heat transfer factor is displayed in Fig. 8. The graph shows that the improved heat transfer factor increases as the inlet velocity increases. And at the same inlet velocity the complex structure has a higher number of enhanced heat transfer factors than the same structure. So the heat transfer efficiency of the complex structure is higher. The presence of cavities in the channel and the inner ribs significantly change the direction of fluid flow so that the angle between the flow line and the isotherm is no longer 90°.

5. Conclusion

A new complicated structure of microchannel heat sink is designed in this work. A double-layer microchannel heat sink with varied upper and lower channels is proposed based on past research. Based on the laws of thermodynamics. Using counter-flow DLCF, a theoretical model is established and the heat dissipation effect of this microchannel heat sink is analysed with the help of numerical simulation methods. Compared with the same structure in upper and lower layers heat sink. The key findings are listed below.

1) The heat transfer efficiency of a complex structured heat sink is greater than that of a heat sink with two identical layers. The highest temperature points are concentrated in the middle of the pipe.

2) The thermal resistance of a double-sided heat sink with complex channels is lower than that of a double-sided heat sink with the same structure. A double microchannel heat sink has a lower thermal resistance than a single microchannel heat sink.

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