Numerical Study of CNT Micro Fin Array for Cooling Application

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Abstract

Heat removing from a microelectronic chip packaging has grand effect on performance and durability of the chip. Today's microchips with high power densities would require efficient methods of cooling. Recently, vertical alignment CNTs, due to their superior thermal, electrical and mechanical properties, was suggested as an effective micro cooler on the level of modern electronics demands. In this paper, the cooling performance of the CNT fin structures is studied numerically. Flow of air was considered as the working fluid flow. CFD simulations have been carried out for a series of CNT micro-fin cooling architectures based on one and two dimensional fin array models. The modeling results indicate that fluid speed is the key factor in heat transfer capacity of the device. Also, the results of 2D carbon nanotube fin array model show more precise and greater thermal performance than that of 1D model. Finally, the examination of pressure drop between inlet and outlet of the cooling device is presented as an important factor which could limit the fluid speed and fin height effect on heat sink performance also investigated.

Keywords: *CFD, cooling applications, CNT, micro fin, simulation*

1. Introduction

Nowadays, in the fast development of electronic circuits, hundreds of thousands of components are integrated on a chip, known as very Large scale Integration (VLSI). This huge system consumes lot of energy cause chip heating. In this situation, thermal issues attract big concern in electronic packaging field. Micro-channel heat sink has been widely used in many applications in electronic product and industry because of its simple construction, fabrication process and high efficient heat transfer level [1]. The conventional micro channel heat sinks are not effective to remove the height thermal induction resulted from VLSI circuit consumption. In this regard recently carbon nanotube micro channel are employed in micro channel to increase its thermal conductivity [2]. Replacing the silicon fins with nanotube fins to enhance the thermal exchange rate between cooling liquid and substrate is one way to overcome the VLSI heat removing problem.

CNTs are made from cylindrical carbon molecules which have superior thermal mechanical and electrical properties make it interesting for lot of various applications. A thermal conductivity up to 6600W/m·K has been reported [3], [4]. CNT as fin material was introduced by [5]. Single phase cooling using CNTs with water as cooling medium was done by Mo [6]. They applied different heat rates to the base of the silicon micro-channel while holding the pressure drop across the device constant. Other investigations about micro-channels have been made in the past years [7]. 2D and 3D model for CNT micro channel heat sink has done by [8]. The fin shape effect in micro channel heat sink and pressure drop and effect of fluid velocity on performance of micro cooler was investigated by them [9-10].

In this work, the micro channel fins consisting of CNTs are used for cooling the micro chip package. The approximated 1D and 2D models were subjected for this systems and the results compared by a more accurate 3D model. The effects of the fins height, also the velocity of the fluids are studied with considering the pressure drop in the system. The results are compared and discussed.

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2. 1D and 2D Fin Array Models

A typical micro-channel cooler configuration is presented in Figure 1. The finned structure is cooled by forced convection phenomena. The produced heat by circuit is conducted through the substrate to the fins where it is transferred to the fluid.

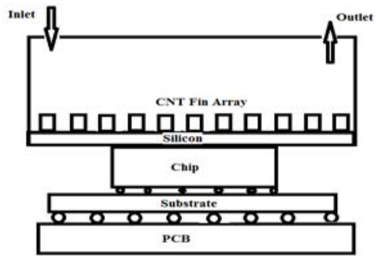


Figure 1. Configuration of the Micro-channel Cooler

The 1D and 2D fin array models are plotted in Figure 2. For these models, Lw is width of the cooler, and L1, L2, L3 are its lengths as indicated in Figure 3. In this model, W_f is width of the fin, and W_{Ch} is width of the channel. Therefore, the width of the CNT array will be L_W-2W_{ch} and its length will be L_2 - L_l -2W_{ch}. The number of fin rows and columns are considered equal to N for a 2D model. However, for 1D model the number of columns is one [11-12].

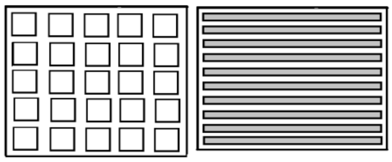


Figure 2. A Schematic of 1D and 2D Fin Array

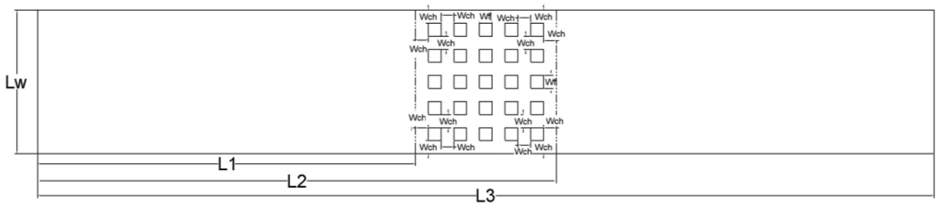


Figure 3. A Schematic of Micro-channel Cooling Assembly with Micro-fin Array Architecture, 2D Fin Array, *M*=5, *N*=5

2.1. Governing Equations

For these simulations the flow regime is considered to be a continuum flow. The flow through this model can be solved using macroscopic relations or the Navier Stokes equations (Equation (1~3)). The basic governing equations for a steady-state, incompressible flows are:
a. Continuity equation

$$(\Delta\rho.u) = 0 \qquad (1)$$

b. Conservation of momentum

$$(\rho u.\Delta u) = -\Delta p + \mu\Delta^2 u \qquad (2)$$

c. Conservation of energy

$$\rho\, c_p (u.\Delta T) = k\Delta^2 T \tag{3}$$

3. CFD Simulation Model

3.1. Geometry Definition

In this study, a typical parallel plate heat sink is showed for the micro-fin. The CNT array was grown on a 12.5mm X 12.5mm area. The thickness of the underneath silicon substrate (base height B.H) is 0.5mm. The channel is long enough so that fully developed flow can be attained. For 1D fin array arrangement from the following figure L=W=12.5mm. Height H= 0.65 mm. Fin pitch (S) and fin thickness (t) are equal to 1mm (Figure 4).

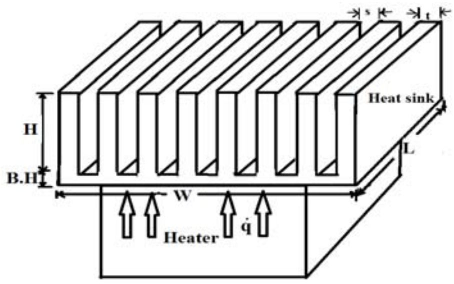


Figure 4. Parallel Plate Heat Sink Showing All the Dimensions

Dimensions of the cooling assembly for 2D micro fin array heat sink are given in Table 1.

Table 1. Dimensions of Cooling Assembly with 2D Micro-fin Architecture

Lw (mm)	Wf (mm)	L1 (mm)	L2 (mm)	L3 (mm)
10	1	30	40	70

3.2. Theoretical Analysis

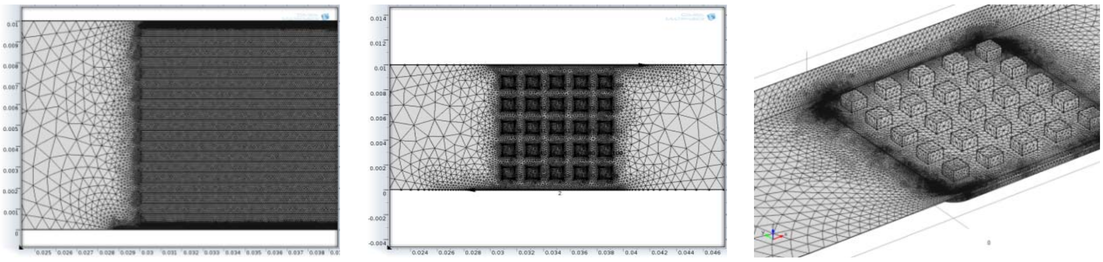
A coolant flows through a micro channel heat sink described before takes away heat from heat component attached below (constant heat flux). The top face is made of insulated material (such as glass) and the bottom material is silicon. The heat transfer contains two parts: conduction in the solid and convection between the solid and coolants. By continuities of temperature and heat flux, the solid region and fluid region are coupled. Some simplifying assumptions are considered as follows [11-12]:

(1) Laminar flow;
(2) Incompressible flow;
(3) Hydro dynamically and thermally fully developed;
(4) No radiation of the wall;
(5) Negligible convection of air out of the cooling assembly;
(6) Constant solid and fluid properties.

In this study two dimensional works for 1D and 2D fin array were investigated. For this cases the energy conservation equation, which can theoretically predict the value of temperature rise between the inlet and outlet, was used for simulation validation in this work [9]. Following the adiabatic boundary conditions in this simulation, the energy supplied by the chip should be equal to the heat removed by the coolant Initial inlet temperature and outlet static pressure values applied to the model are assumed for all simulations to be 20 °C and outlet pressure 0 Pa, respectively. To monitor the heat transfer coefficient and the heat transfer rate, the outer walls of the channel are set to be adiabatic. No-slip boundary conditions and no interfacial resistance are assumed at the wall/fluid interface. Water is used as the working fluid flowing through this heat exchanger with different velocities 0.1, 0.25, 0.5 and 0.75 m/s through the inlet of the channel. These simulations are in the single phase regime and fluid properties are kept constant throughout the simulations. Water flows past the pin fins carrying heat subjected by the bottom surface. A constant heat flux 15 W/cm^2 is applied to a 12.5 $\times$12.5 mm^2 area at the bottom of the channel.

3.3. Mesh Generation

Conjugate heat transfer module is used to treat the solid and fluid as a unitary computational domain, and to solve the above governing equations simultaneously. The mesh in every channel should be fine enough, since the velocity gradient is very high in z-direction (400 W/m.K) and low in x and y direction (40 W/m.K) (Figure 5).

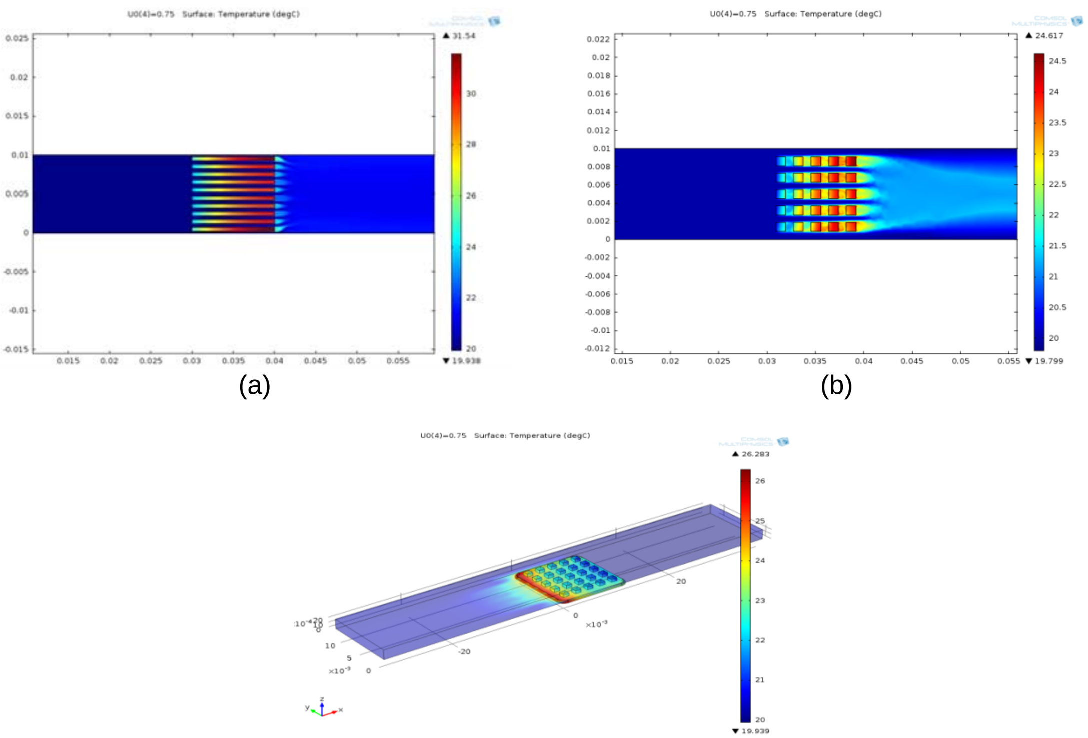


a B C

Figure 5. 1D, 2D and 3D Fine Mesh Generation at Fin Assembly was Showed in a, b and c Respectively

4. Results and Analysis

4.1. Fluid Speed Effect



(a) (b)

(c)

Figure 6. Temperature Distribution for Rectangle Fin Array; (a) 1D fin array, (b) 2D fin array and (c) 3D fin array

In the first investigation, temperature distribution in 1D, 2D and 3D CNT fin array for different fluid flow velocity 0.1, 0.25, 0.5 and 0.75 m/s were obtained. Investigation showed that fluid speeds were key factor of heat transfer as simulation result shows that maximum fin temperature decreases with increase of fluid velocity. Temperature distributions for 1D, 2D and 3D fin array was showed in Figure 6. As is seen maximum temperature in 2D fin array is much close to 3D fin array and be better approximation than 1D fin array for 3D fin array. Therefore, the cooling capability of 2D carbon nanotube fin array is more efficient than that of 1D carbon nanotube fin array.

4.2. Fin Height Effect

In the second investigation, effect of different fin height in heat sink thermal performance was investigated. Fins with 0.5, 0.65, 0.75 and 1mm heights were compared with unfinned heat sink. As indicated in Figure 7, with increasing the fin height, maximum temperature for the heat sink decreases, which shows better heat removing. The effect can be explained by augmentation of the contact surface area between fluid and the fins. The latter results in better convection heat transfer in the system.

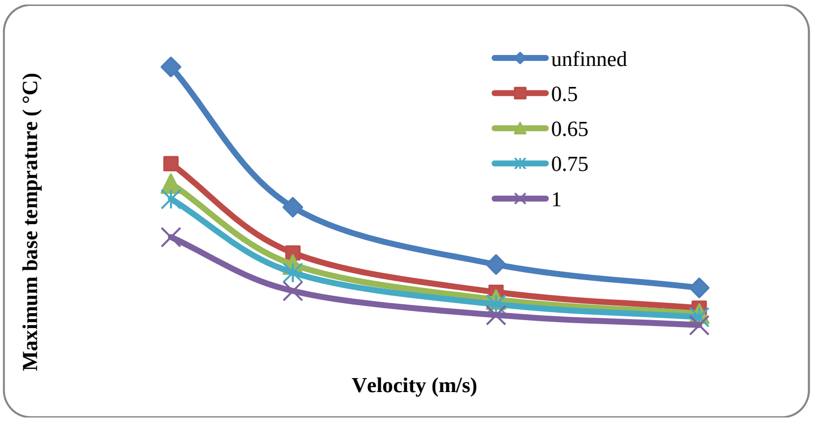


Figure 7. Maximum Silicon Base Micro Channel Heat Sink with Different Inlet Fluid Velocity

4.3. Pressure Drop Effect

In the final investigation, pressure drop between inlet and outlet of micro-channel heat sink were obtained. Investigation showed that pressure drop increase with increase inlet fluid velocity. Figure 8 shows the variation of pressure drop of three fin array models under the flow rate from 0.1m/s to 0.75 m/s. These findings show that 3D fin array model have higher pressure drop than 1D and 2D fin array.

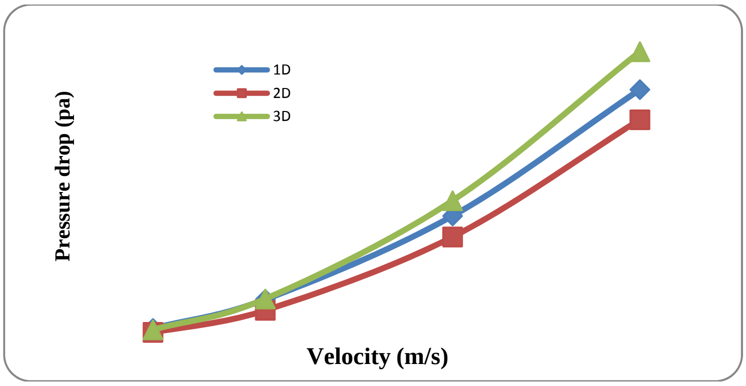


Figure 8. Pressure Drop in Different Velocity for Various Fin Height

As it was mentioned before, the higher fluid velocity results higher pressure drop in the system. The effect of various fin height on pressure drop is studied, also, versus different fluid velocity. The results are presented in Figure 9. It is seen that with increasing the fin height the negative effect of velocity augmentation increases. This means that pressure drops even more for longer fins. With increasing the fin height, maximum temperature for the heat sink decreases, which shows better heat removing but pressure drop increase dramatically. For have better performance should be optimum case between decrease temperature by increasing velocity and increasing pressure drop with increase fin height in micro channel heat sink.

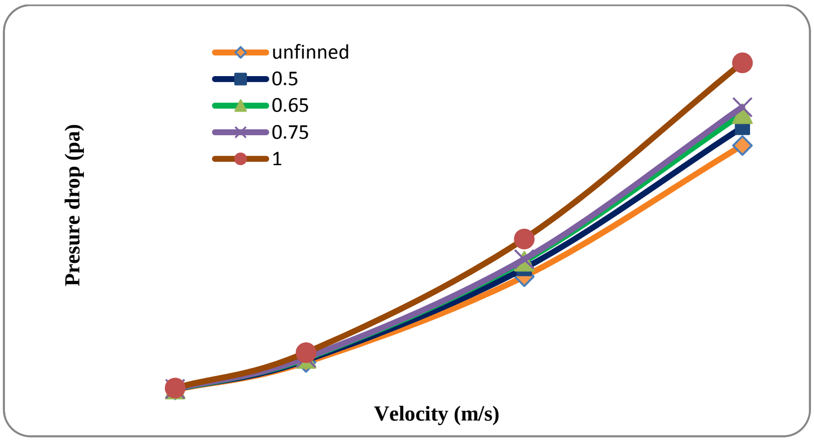


Figure 9. Pressure Drop in Different Velocity for Three Fin Array Models

5. Conclusion

Micro-channel heat sink has been widely used in many applications in electronic product and industry because of its simple construction, fabrication process and high efficient heat transfer level. The simulation results in this work indicate that all the heating power is removed by the liquid mass flow. The fin height in micro-fin array and the fluid velocity are important factors for heat removal. Heat transfer capability of the micro-fin is dependent very much on the inlet liquid speed. The cooling capability of 2D carbon nanotube fin array is more efficient than that of 1D carbon nanotube fin array. Pressure drop increase with increase inlet fluid velocity and 3D fin array model have higher pressure drop than 1D and 2D fin array which is not good for the CNT micro-fin array. With increasing the fin height, maximum temperature for the heat sink decreases, which shows better heat removing but pressure drop increase dramatically. For have better performance should be optimum case between decrease temperature by increasing velocity and increasing pressure drop with increase fin height in micro channel heat sink.

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