CFD Analysis for 2D-Micro fin Array with Carbon Nanotube Structured Surfaces for Cooling Applications

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Abstract

The next generation microchips with high power densitieswould require novel methods of cooling. Micro channelsprovide an effective way of cooling microchips. CNTs are made from cylindrical carbon moleculeswhich are very special in thermal, electrical and mechanical properties. A thermal conductivity up to 6600W/m·K hasbeen reported. The1D and 2D CFD simulations have been carried out for aseries of CNT micro-fin cooling architectures based on one and twodimensional fin array models in this paper.The analysis indicates that fluid speed is thekey factor of heattransfer and 2D carbon nanotube fin array shows greaterthermal performance than that of 1D carbon nanotube fin array. The pressure drop between inlet and outlet of the coolingdevice is an important cause to limit the fluid speed.

Key words:CFD,Cooling Applications,CNT, Micro fin, Simulation,

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1. Introduction

The next generation microchips with high power densities would require novel methods of cooling. Since Gordon Moore proposedthat transistors on chips would double every two years (Moor, 2005). This has become a law which witnessed the fast development of electronics. Nowadays hundreds of thousands ofcomponents are integrated on a chip at a millimeter scale.When chip size decreases with the increasing components, thepower density is also increased dramatically. In this situation,thermal issues attract big concern in electronic packagingfield.Micro-channel heat sink has been widely used in manyapplications in electronic product and industry because of itssimple construction, fabrication process and high efficient heattransfer level. The micro-pin-fin heat sink also earned muchattention and applications where high heat transfer rates arerequired. Compared to the channel structure, the pin-fin arrayhas more area to enhance the heat transfer.CNTs are made from cylindrical carbon molecules which are very special in thermal, electrical and mechanical properties. A thermal conductivity up to 6600W/m·K has been reported (Marconnet et al. 2012, Hone 2004). Due to the superior thermal conductivity of CNT and the advantages of micro-channel, the liquid cooling withcarbon nanotube micro-fin architecture has been consideredas a potential candidate that support a proper occasion forgrowth of new compact cooling devices. CNT as fin material was introduced by Liu et al. (2004). Single phase cooling using CNTs with water as cooling medium on the other hand was researched by Mo et al. (2005). They applied different heat rates to the base of the silicon micro-channel while holding the pressure drop across the device constant.A lot ofinvestigations about micro-channels have been undertaken in the pastyears (Shenoy *et al*. 2011). However, as the trends in the electronics industry moves towards higherpackaging density,the high-pressure drop problem limits theperformance of traditional silicon heat sink. Replacing the silicon finswith nanotube fins to enhance the thermal exchange rate betweencooling liquid and substrate is one way to overcome this problem.Channels are etched and covered by Plexiglas on the top and ultimatelyformed a complete structure. The basic principle of micro-channelheatsink is that bottom is in touch with the heat and fluid flows throughthe entrance to the export to take away heat. In practice, with increasingheat, when the micro-cooler maximum temperature exceeds the fluid'stemperature, convection heat is generated between wall and fluid untilthe heat balance is stabilized and micro-cooler works into the stableworking condition (Wang *et al.*,2009; Zhong *et al.*,2007) Replacingthe silicon fins with nanotube fins or growing aligned nanotubes on thewhole substrate to enhance the thermal exchange rate between coolingliquid and substrate is one way to overcome this problem (Dietz *et al*., 2008).

2.Micro-channel theory

A typical micro-channelcooler configuration is a finned structure, which is cooled by forced convection (Fig.1). The power is dissipated on thecircuit side and the heat is conducted through the substrate tothe fins where it is transferred to the coolant. The majoradvantage is the high heat transfer coefficient and possiblewafer-level integration with chips.

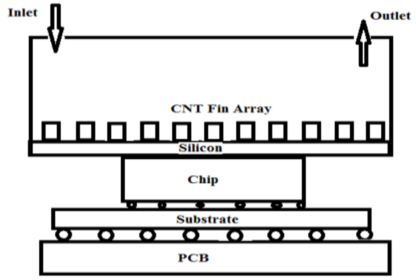

Fig.1. Configuration of the micro-channel cooler

Two types of fin array, we calledID nanotube fin array and 2D nanotube fin array areplotted in this figure2.The geometry parameter Lw is width of coolermodel, the length L1, L2, L3 of cooler model are defined asmarked in Fig.3, respectively. W_f is width of fin, and W_{Ch}width of channel (Zhong et al. 2007). It can be seen from Fig.3 that the width ofCNT array architecture isL_W-2W_{ch} and the length of CNTarray architecture is L_2- L_I-2$W_{ch.}$ The geometry parameters M and N are noted to describethe micro fin array and specify the number of fin rows and thenumber of fin columns, respectively. The N = M is adoptedfor 2D fin array in this primary case study. The fin width $W_f$and channel width Wch, both of rows and of columns in 2D finarray, are taken to be equal in this case study for convenience. From Fig.3, the channel width Wch = Lw/(2M+1) under thecondition W_f = Wch in this study. Dimensions of the coolingassembly are given in Table 1.The N=1 is reflected forID fin array and N>1 for 2D fin array in this primary one dimensionalCFD simulation work, and N = M is adopted for2D fin array in this primary case study. The fin width W_f andchannel width W_{Ch}, of rows in ID fin array and both of rowsand of columns in 2D fin array, are taken to be equal in this case study.

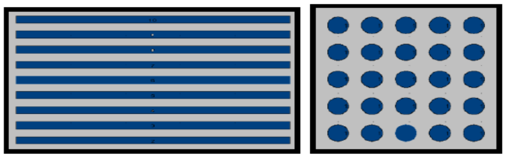

Fig 2.A schematic of 1D and 2D fin array

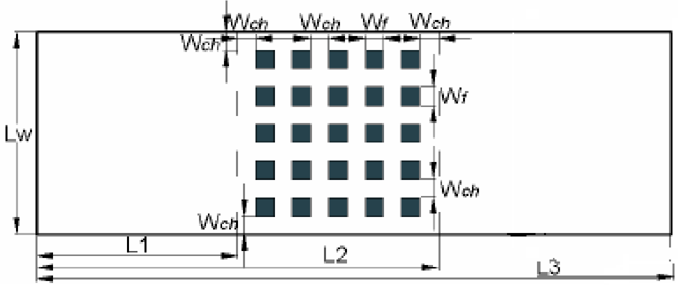

Fig 3.A schematic of micro-channel cooling assembly with micro-fin Array architecture, 2D fin array, *M*=5, *N*=5

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

Table 1.Dimensions of cooling assembly with micro-fin architecture

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 usingmacroscopic relations or the Navier Stokes equations (Eq.1~3). The basicgoverning equations for a steady-state, incompressible flows are:

Continuity equation

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

Conservation of momentum

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

Conservation of energy

$$\rho c_p (u.\Delta T) = k\Delta^2 T \qquad (3)$$

3. CFD Simulation Model

3.1. Geometry definition

In this case study, a typical parallel plate heat sink is showed for the micro-fin. The CNT array was grown on a 10 mm X 10 mm area. The thickness of the underneath silicon substrate (base height B.H) is 50 µm. The channel is long enough so that fully developed flow can be attained. For 1D fin array arrangement from the following figure L=W=10 mm. Height H= 0.65 mm. Fin pitch (S) and fin thickness (t) are equal to 0.5 mm (Fig. 4).

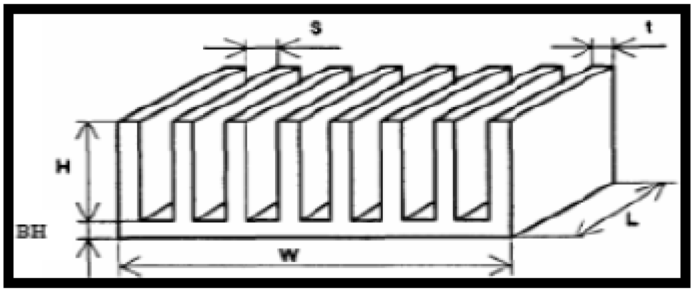

Fig 4.Parallel plate heat sink showing all the dimensions

In this paper,thermal conductivity of CNT array assumed 400 W/m.k in x and y-directions and 40 W/m.k in z-direction(Wang et al., 2009; Ismail et al., 2011) .Table 1 has a list of properties pertaining to the different fin materials that used in this paper.

Fin material	K $\left({}^{W}\!/_{m.k}\right)$	$c_p\left({}^{J}\!/_{kg.k}\right)$	$\rho\left({}^{kg}\!/_{m^3}\right)$
CNT	400	450	1300
Aluminum	273	903	2702
Silicon	148	712	2330

Table 2.Material properties for fin material comparison

3.2. Theoretical Analysis

A coolant flows through a micro channel heat sinkdescribed before takes away heat from heat componentattached below (constant heat flux). The top face is made ofinsulated material (such as glass) and the bottom material issilicon. The heat transfer contains two parts: conduction inthe solid and convection between the solid and coolants. Bycontinuities of temperature and heat flux, the solid region andfluid region are coupled. Some simplifying assumptions areconsidered as follows:

(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 (Mahbub et al. 2011). Following the adiabatic boundary conditions in this simulation, the energy supplied by the chip should be equal to the heat removed by the coolantInitial inlet temperature and outlet static pressure values appliedto the model are assumed for all simulations to be 20°Cand 0 Pa, respectively. To monitor the heat transfer coefficientand the heat transfer rate, the outer walls of the channel are setto be adiabatic. No-slip boundary conditions and no interfacialresistance are assumed at the wall/fluid interface. Water is usedas 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 thechannel. These simulations are in the single phase regime and fluidproperties are kept constant throughout the simulations. Waterflows past the pin fins carrying heat subjected by the bottom surface.A constant heat flux 15 W/cm^2 is appliedto a 10×10 mm^2 area at the bottom of the channel.

3.3. Mesh generation

Conjugate heat transfer moduleis used to treat the solidand fluid as a unitary computational domain, and to solve theabove governing equations simultaneously (Figure 5). The mesh inevery channel should be fine enough, since thevelocity gradient is very high in z-direction (400 W/m.K) andlow in x and y direction (40 W/m.K) (Figure 6).

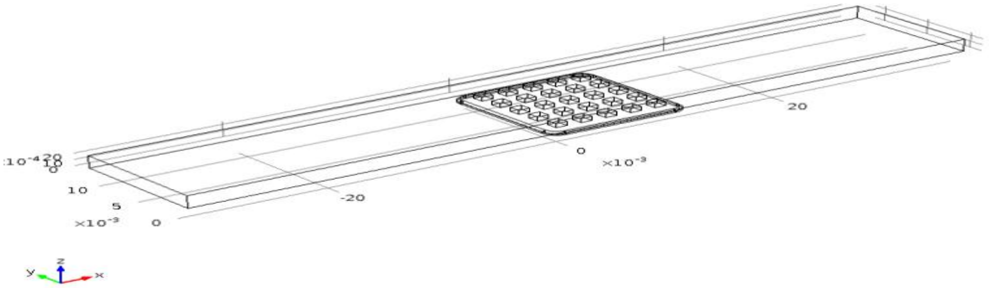

Fig 5.3D model at fin assembly

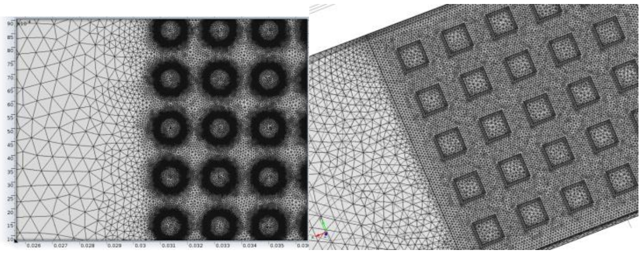

Fig 6.2D and 3D fine mesh generation at fin assembly

4. Results and Analysis

4.1. Fluid speed effect

In thefirst 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 maximum and simulation result shows that maximum fin temperature decreases with increase of fluid velocity. Fin array of1D fin array were higher than maximum fin array of 1D, 2D and 3D fin array (Figures 7~9). Therefore, the cooling capability of 2D carbon nanotube fin array is more efficient than that of 1D carbon nanotube fin array.

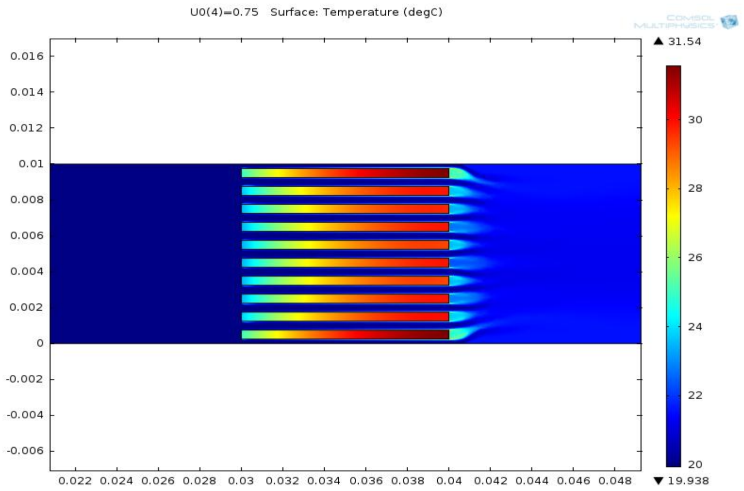

Fig 7.2D Temperature distribution for 1D circular fin array

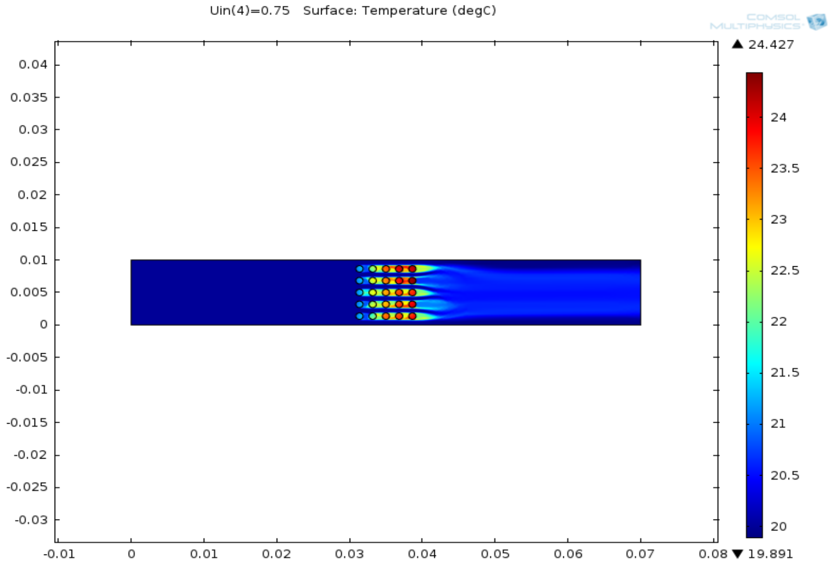

Fig8.2D Temperature distribution for 2D circular fin array

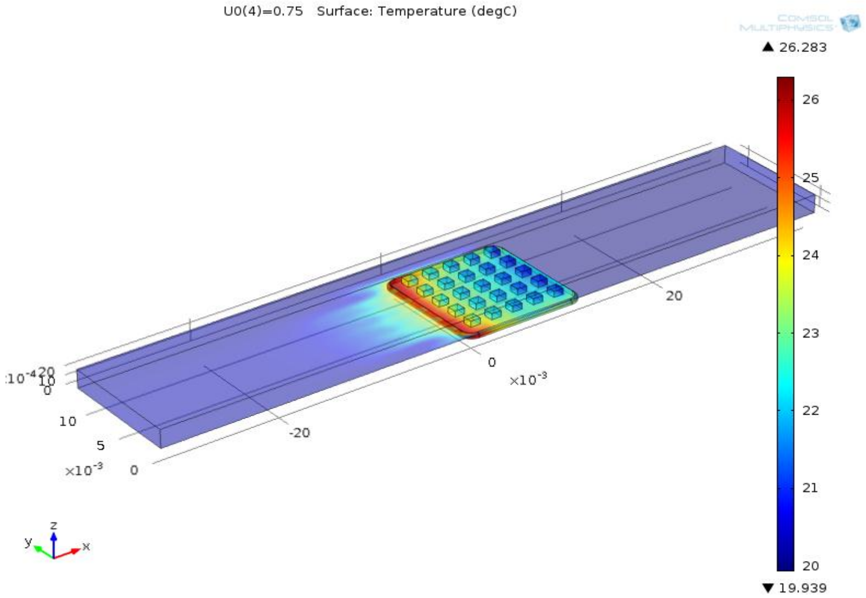

Fig9.3D Temperature distribution for 3D circular fin array

4.2. Fin material effect

In the second investigation, different material used as fin array material as CNT, silicon and aluminum.Table 1 has a list of properties pertaining to the different fin materials that used in this paper. As be seen in Fig.9 CNT fin array have better thermal performance than silicon and Aluminum fin array but effect of different material was not very significant.These findings show that the chosen fin material had littleeffect on the maximum fin temperature values. In this study, CNTs are modeled as a solidfin but in reality the fins are more of a porous media that containsmall gaps where the fluid can penetrate. The nanotubes can alsoinitiate nucleation sites initiating boiling and therefore enhancingheat transfer. Because of this, the results for the CNT fins are underestimatedusing this program.

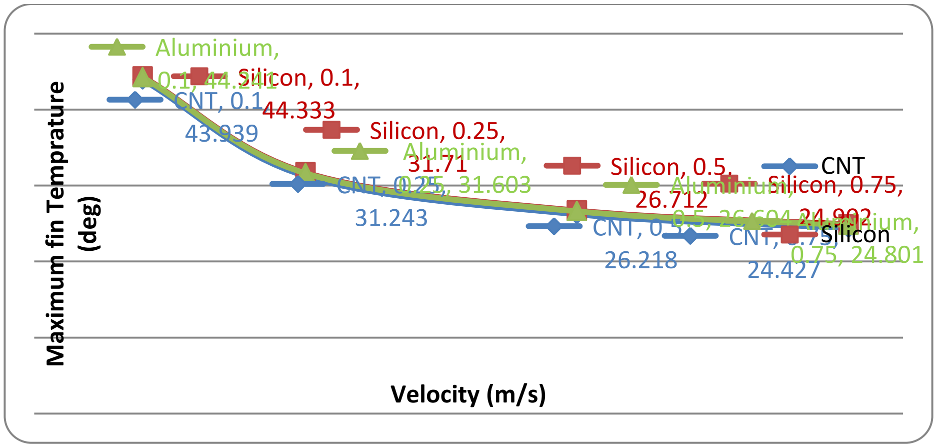

Fig 9.Maximum fin array temperatureversus velocityfor selected fin material Properties

4.3. Pressure Drop effect

In the finalinvestigation, pressure drop between inlet and outlet of micro-channel heat sink were obtained. Investigation showed that pressure drop increase with increase inlet fluid velocity. Fig.10 shows the variation of pressure drop of three fin array modelsunder 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.

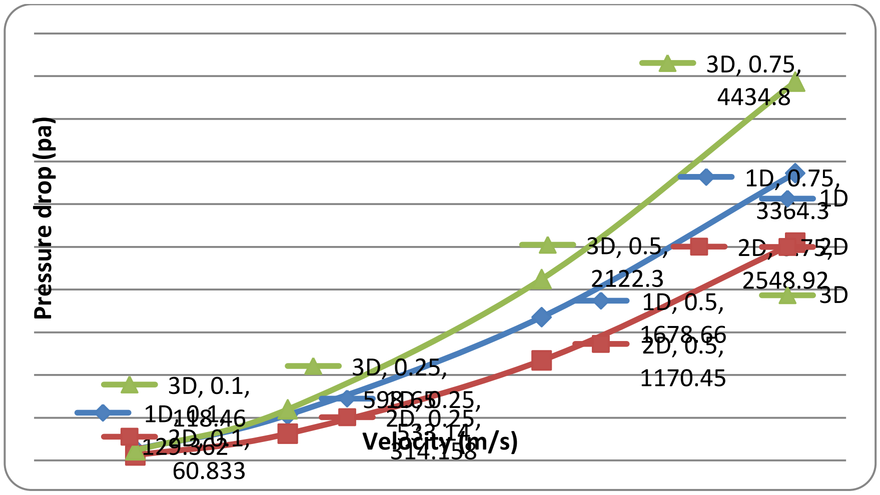

Fig 10.Pressure drop in different velocity for three fin array models

5. Conclusions

The simulation results in this work indicate that all the heating power is removed by the liquid mass flow. The material 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. CNT micro fin have better thermal performance than silicon and aluminum fin array but effect of different material was not very significant.In this study, CNTs are modeled as a solidfin but in reality the fins are more of a porous media that containsmall gaps where the fluid can penetrate. The nanotubes can alsoinitiate nucleation sites initiating boiling and therefore enhancingheat transfer. Because of this, the results for the CNT fins are underestimatedusing this program.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.

References

Dietz, C.R., and Joshi, Y.K. (2008), Single-phase forced convection inmicrochannels with carbon nanotubes for electronics cooling applications, *Nanoscale and Microscale Thermophysical Engineering. 12 (3), 251–271*

Farhad Ismail,Rashid A.I, and Mahbub,M. (2011). CFD Analysis in a Liquid-Cooled Carbon Nanotube BasedMicro-channel Heatsink for Electronic Cooling. *IACSITInternational Journal of Engineering and Technology, Vol. 3, No. 5*

Hone et al. (2004), *Carbon Nanotubes: Thermal properties*, Encyclopedia of Nanoscience and nanotechnology, pp. 603-610

Intel. (2005). Excerpts from A Conversation with Gordon Moore: Moore's Law

Kordás. K et al. (2007), Chip cooling with integrated carbon nanotube microfin architectures. *APPLIED PHYSICS LETTERS 90, 123105*

LiuJohan. (2008), Recent Progress of Carbon Nanotubes as Cooling Fins in Electronic PackagingInternational Conference on Electronic Packaging Technology & High Density Packaging (ICEPT-HDP)

Liu et al. (2004),Integration Nano Carbontubeswith Microchannel Cooler. SMIT Center and Division of Electronics ProductionChalmers University of Technology 431 53 Mondal, Sweden

Marconnet et al. (2012),Thermal Conduction Phenomena in Carbon Nanotubes and Related Nanostructured Materials. *Department of Mechanical Engineering Stanford University, Stanford, CA 94305*

Mo et al. (2005), Integrated Nanotube Microcooler forMicroelectronics Applications, *Electronic Components andTechnology Conference*, pp.51-54

Shenoy et al.(2011),Minichannels with carbon nanotube structured surfaces for cooling applications. *International Journal of Heat and Mass Transfer 54 5379–5385*

Wang, S et al.(2009) , A Study ofHeat TransferCharacterstics of the Micro- Channel Heatsink,*International Conference on Electronic Packaging Technology & HighDensity Packaging, pp.255-259.*

Zhong, X et al. (2007), A Study of CFD Simulation for On-chip cooling with 2D CNT Micro-fin Array, *International Symposium on High Density Packaging and Microsystem Integration. China, pp.442-447*