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Numerical investigation on microelectronic chip cooling using multiple orifice synthetic jet actuator based on theory field synergism

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Abstract

Synthetic jet is applied to the field of heat and mass transfer, because the periodical suck and blow enhances forced convection heat transfer. A multiple orifice synthetic jet actuator (SJA) is designed for the cooling of microelectronic chips. By using fin, it can achieve higher effectiveness of heat transfer with a combination of active and passive scheme in heat dissipation. Numerical simulation of the flow field of the multiple orifice SJA is performed to analyze the mechanism of the heat dissipation. Based on the above work, numerical simulations presenting the effects of heat dissipation with different flat-to-orifice distances are performed in this study. The theory Field Synergism of the optimization of convection heat transfer is introduced to evaluate the effects of the parameters on heat transfer by comparing the magnitude of the integral value. The results verify that the larger the integral value is, the higher the heat transfer coefficient is. And there is an optimum impinging distance at which the synergy degree between velocity field and temperature gradient field reaches its peak and the heat transfer coefficient is the highest.

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Keywords: synthetic jet; heat dissipation; active and passive combined scheme; Field Synergism.

1. Introduction

As the microelectronic technology develop fast in recent years, the cooling of electronic components has become an essential part of electronic production. Electronic components have an appropriate working temperature range.

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When they work at the temperature beyond the range, they will break down. Among the failure cases of electronic components, 55% [1] are caused by temperature.

Compared with the traditional forced-air cooling, impinging synthetic jet cooling has more advantages such as no piping, no rotating parts, high reliability and high cooling efficiency, easy control and flexible configuration, etc.

Electronic cooling using synthetic jet has made great progress. A large number of investigations have been carried out on impinging gas jet heat transfer over the last decades. Synthetic jet has great advantages in electronic components' cooling due to its periodical suction and blowing and the vortex generated in this process. Mahalingam and Glezer [2] designed cooling devices based on SJA for high power electronic components, and analyzed the thermal characteristics. They found that the heat removed by synthetic jet is 2.5 times of steady heat dissipation through a pipe. Chandratilleke and Dibakar [3] designed a cooling device for CPU based on a SJA. It performed better in heat dissipation than natural convection cooling or traditional cooling by fan. Zhang and Tan [4] investigated the heat transfer characteristics of the target plane and the flow characteristics of impinging synthetic jets actuated by piston.

However, there are still many problems in the current cooling technology with synthetic jets, such as limited heat dissipation areas and low energy utilization efficiency. In order to solve these problems, a multiple orifice SJA with a single diaphragm and two chambers is designed for microelectronic chip cooling in this study. The detailed numerical simulation results are presented in the paper.

2. Numerical model

Based on the Dual SJA (DSJA) [5], a multiple orifice SJA (SJA) with a single vibrating diaphragm and two chambers is designed. The physical model is shown in Fig. 1.(a), the size of the outside orifices are $1.5mm \times 1.5mm \times 3mm$, and size of inside orifices are $2.5mm \times 2.5mm \times 3mm$. The 3D numerical computing domain and mesh of the multiple orifice SJA is shown in Fig. 1.(b).The number of mesh elements is 1218967.

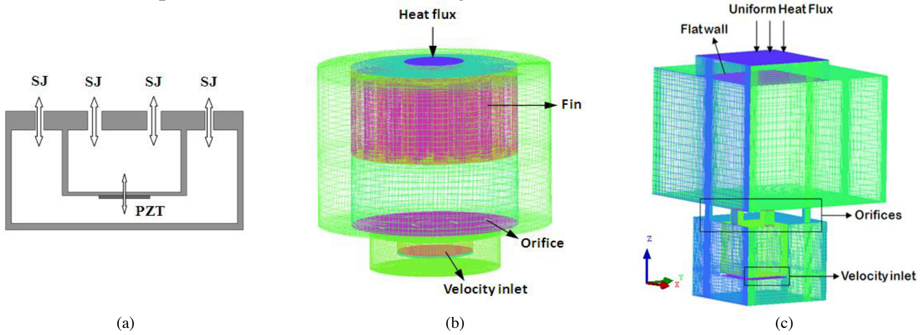


Fig. 1. Numerical model: (a)physical model; (b)computing domain and mesh of multiple orifice SJA; (c)simplified 1/4 domain and mesh

2.1. Simplification of the 3D model

Because of the huge number of mesh elements in the heat dissipation 3D numerical simulation, and the really short time step, the whole computing cycle can be very long. To save time and the computing resource, fin surfaces are simplified to be a flat plane. Meanwhile, an equal area of the flat plane is required to make sure that the heat dissipation corresponds to that of the fin surfaces. The 1/4 computing domain of the simplified model is shown in Fig. 1 (c), resulting in the number of mesh elements to be 510895.

In order to get the equal area of the flat plane, fin efficiency η_f is introduced here. η_f represents the coefficient of effective heat dissipation of fin [6] and can be defined as:

$$\eta_f = \Phi_f / \Phi_{asu} \tag{1}$$

where, Φ_f is the heat dissipation of fin, and Φ_{asu} is the heat dissipation assuming the whole fin surfaces were the same temperature as the fin base. Fin efficiency can be checked by mH value in related table.

Under steady conditions, heat fluxes Φ in each step during the heat transfer are the same as shown in Fig.2and as the heat transfer coefficient is associated with A_i , it is assumed that the temperature of the whole fin surfaces is the same as the fin base. Define $\beta = A_o / A_i$ as the fin effect coefficient, and we get:

$$k_f = 1/\left(\frac{1}{h_i}+\frac{\delta}{\lambda}+\frac{A_i}{h_o\eta_o A_o}\right) = 1/\left(\frac{1}{h_i}+\frac{\delta}{\lambda}+\frac{1}{h_o\eta_o\beta}\right) \tag{2}$$

$$A_{eq} = \frac{\Phi}{t_{fi}-t_{fo}}\left(\frac{1}{h_i}+\frac{\delta}{\lambda}+\frac{1}{h_o\eta_o\beta}\right) = k_1 f\left(\eta_f,\beta\right) \tag{3}$$

From the derivation above, we can see that A_{eq} is a function of A_o, that means the fin model can be simplified to be a flat plane for the sake of saving computing time and resource.

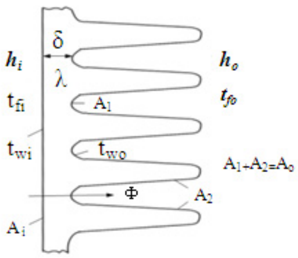
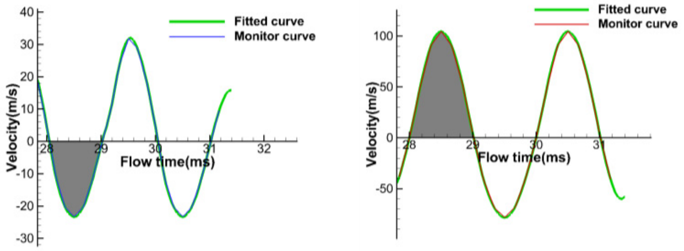


Fig. 2. Heat transfer through fin surface



(a) (b)

Fig. 3. Stroke of inside orifices and the outside orifices

2.2. Governing equations, boundary condition and solution

Governing equations are as follows:

$$\begin{cases} \nabla\cdot\bar{u} = 0 \\ \rho\dfrac{\partial\bar{u}}{\partial t}+\rho\bar{u}\cdot\nabla\bar{u} = -\nabla\bar{p}+\left(\mu_1+\mu_t\right)\nabla^2\bar{u} \\ \dfrac{\partial T}{\partial t}+u_j\dfrac{\partial T}{\partial x_j} = \alpha\dfrac{\partial}{\partial x_j}\dfrac{\partial T}{\partial x_j}-\dfrac{\partial\overline{u_j'T'}}{\partial x_j} \end{cases} \tag{4}$$

The boundary conditions of the vibrating diaphragm is based on the—X-L model. The thermal boundary of the microelectronic chip is given by constant heat flux of $2.1\times10^5 W/m^2\cdot K$. Coupled boundary for the fin surfaces in the flow field is stationary and there is no slip wall boundary for other solid surfaces.

As for computing solution, second order upwind scheme and second implicit scheme are adopted, PISO for velocity and initial pressure field correction, iterating residual is 1×10^{-4}, except for energy residual 1×10^{-6} .

With the definition of synthetic jets stroke [7], analogy is made to get the stroke of multiple orifice SJA as shown in Fig. 3. The stroke of inside and out orifices are L_{IN}=21 *mm*, L_{OUT}=63 *mm*. Four cases of different flat-to-orifice distance: *L*= 25 *mm*, 40 *mm*, 55 *mm*, 65 *mm*, are selected to discuss the influence of the impinging distance on the heat dissipation efficiency of the multiple orifice SJA.

3. Results and discussion

3.1. Flow field of the multiple orifice SJA

The flow field of a multiple orifice synthetic jet is obviously periodical in Fig. 4 Periodical suction and blowing take place in the outside and the inside orifices. The maximum velocity magnitude of a cycle is up to 100 *m/s*, and the maximal stroke is about 63 *mm* as mentioned before. The periodical suction and blowing in a cycle and the merging and rolling up of the vortex pairs are essential to enhance the forced convection heat transfer. The multiple orifices of this SJA provide larger area of impinging than traditional SJA, heat dissipation is enhanced in a more uniform way. And the configuration of one vibrating diaphragm and two chambers improves energy utilization efficiency.

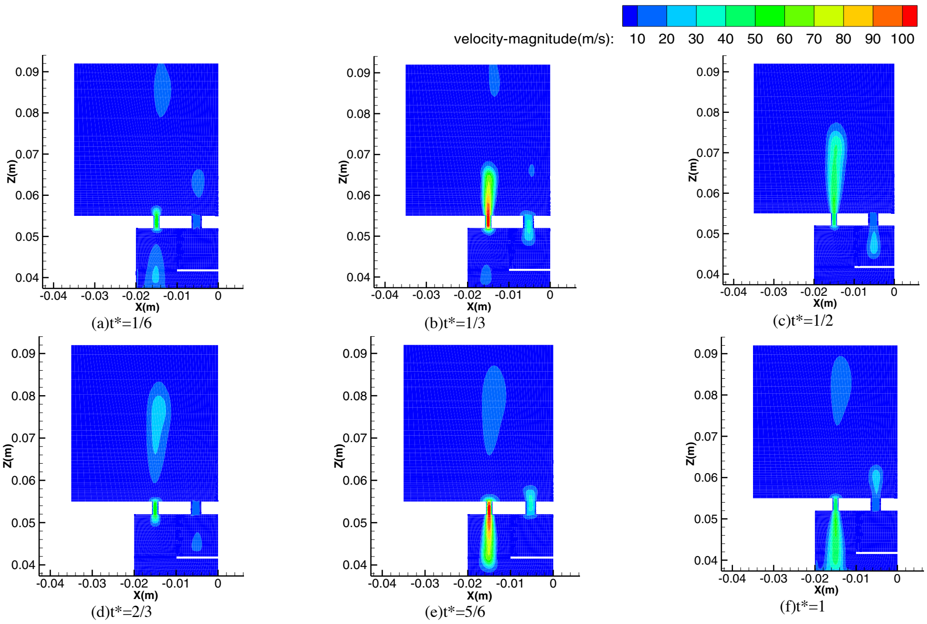


Fig. 4. Velocity magnitude of multiple orifice SJA in a cycle

3.2. Effect of flat-to-orifice on heat dissipation

Based on the stroke and flow field characteristics, 4 cases are simulated to investigate the effect of the flat-to-orifice distance on heat dissipation. Time- averaged Nusselt numbers (Nu) are shown in Fig. 5, and the average Nu of the impinging surface is calculated based on interpolation in Fig. 6. We can deduce from the fitted curve in Fig. 6 that the optimum flat-to-orifice distance for heat dissipation is between 40 to 55*mm*. It is found that with larger flat-to-orifice distance, e.g. in case L65, the edge of the heated surface achieves higher Nu.

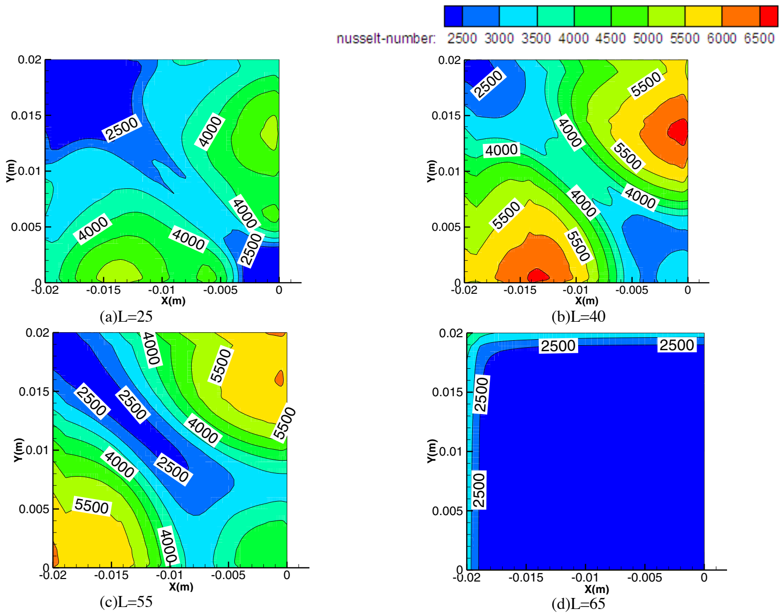


Fig. 5. Nu on the impinging surface at different flat-to-orifice distance

3.3. Discussion based on the theory Field Synergism

The theory Field Synergism, proposed by Professor Guo [8], says that heat transfer can be enhanced when the velocity field and temperature gradient field is synergetic with each other. To describe and compare the level of the synergism, an integral value I is defined as below:

$$I = \int_0^{\delta_{t,x}} (\boldsymbol{U} \cdot \nabla \boldsymbol{T}) dy \tag{5}$$

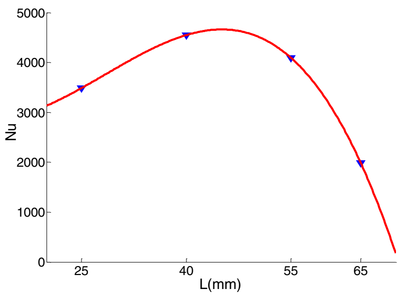


Fig. 6. Fitted average Nu on the impinging surface at different flat-to-orifice distance

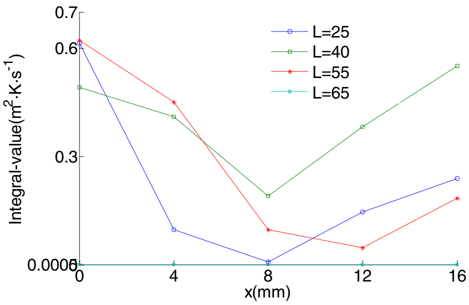


Fig. 7.The integral value I at different flat-to-orifice distance in separated sections

Fig. 7 shows the integral value I of 5 sections (orthogonal with the X axis) near the flat wall zone at different flat-to-orifice distances. Taking into consideration of the computing cost, section areas are $3mm \times 40mm$, thermal boundary layer is included in this area. The results in Figure 7 coincide with that in Fig. 5, section x=8 mm has the lowest Nu and lowest integral value I . For different impinging distances, heat transfer efficiency are both very low at case L25 and case L65. In case L25, the impinging surface is very close to the jet exit, and there isn't enough room for jet velocity magnitude to reach its peak. In case L65, the impinging distance is so long that the strength of vortex pairs start to weaken, and heat is not efficiently removed.

4. Conclusion

A multiple orifice SJA has been designed in this work for the sake of increasing the heat dissipation area and improving the energy utilization efficiency. Tt has a single vibrating diaphragm and two chambers. 3D numerical simulations of the flow field of the multiple orifice SJA and the microelectronic chip heat dissipation have been performed. It is noticed that optimum flat-to-orifice distance for heat dissipation is between 40 to 55 mm, where the Nu reaches peak value and the integral value I is the biggest. It is proved that field synergy principle is a novel method to evaluate the heat dissipation efficiency and to guide in designing of forced-convection heat transfer in the future work.

References

[1] Janicki. M, Napieralski. A, “Modeling electronic circuit radiation cooling using analytical thermal model,” Microelectronics Journal, vol.31, 2000,pp. 781-785.
[2] R. Mahalingam, A. Glezer, “Design and thermal characteristics of a synthetic jet ejector heat sink,” Journal of Electronic Packaging, vol. 127, 2005, pp. 172-177.
[3] Tilak T C, Dibakar R. “Thermal performance of a double-action pulsed jet cpu cooler,” IEEE 15th Electronics Packaging Technology Conference (EPTC), 2013.
[4] Tan, X M. Zhang, J Z. “Flow and heat transfer characteristics under synthetic jets impingement driven by piezoelectric actuator,” Experimental Thermal and Fluid Science, vol.48, 2013, pp. 134-146.
[5] Yang, S M. Tao, W Q. Heat transfer, Higher Education Press, 3rd Edition, December, 2003.
[6] Luo, Z B. Xia, Z X. Liu, B. “New generation of SJAs,” AIAA Journal, vol. 44, 2006, pp. 2418-2419.
[7] Deng. X, Xia. Z. X, Luo. Z. B, “Analysis of impact factors on vectoring characteristic of dual SJA,” Journal of Propulsion Technology, vol.35, 2014, pp.1131-1136.
[8] Guo. Z Y, “Physical mechanism and control of heat convection: synergy between velocity field and heat flow field,” Chinese Science Bulletin, vol. 45, 2000, pp. 2118-2122.