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A Mathematical Model for Optimizing the Structure of A Flat Micro Heat Pipe with Fiber Wick

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Abstract. A three-dimensional mathematical model is developed for a kind of micro heat pipe with fiber wick. The effects of phase changing, the contact angle, gravity, and heat conducting between the fibers are accounted in the model. The governing equations are formulated in the control volume and calculated by iteration. The calculated results of the model present the velocity of the working material and the phase changing rate of the liquid. The structure of the micro heat pipe is optimized by the calculated results of the model and the two levels of fibers are enough for this kind of flat micro heat pipe.

Introduction

The amount and density of electronic components in VLSI chips sharply increases on modern integrated circuits. The heat generated in these chip results in high-operating temperature if not removed, which will degrade the speed and the stability of the electronic devices [1]. Furthermore, the thermal stresses inherent within a chip during operation typically result in failure caused fatigue of the mechanical devices or connections [2]. Cotter first introduced the concept of micro heat pipe for the dissipation and removal of heat. Then micro heat pipe is widely used in many fields because it has the merit of high efficiency, no noise, and without power [3, 4]. Recently many micro heat pipes use fibers as wick structure to increase the characteristic, and fiber wick becomes one of the significant researches [5, 6].

Precious mathematical model is not suitable for micro heat pipe with fiber wick, so developing a new mathematical model to analyze and optimize the fiber wick is necessary [7]. A three-dimensional mathematical model is developed for the fiber wick in this paper. The effects of phase changing, the contact angle, gravity, and heat conducting between the fibers are accounted in the model. The governing equations are formulated by conservation of mass, momentum and energy in three dimensions. The model is calculated by iteration and the results show that the first and second level of the fibers in the micro heat pipe is efficient and the third level is unnecessary.

Structure of the Micro Heat Pipe

This kind of micro heat pipe is designed to use glass fibers as the wick structure. The fibers are pushed closely in the copper plate and front plate is packaged on the fibers presented in Fig. 1. The shape of the front plate is shown in Fig. 2, and the front plate can not only push the fibers closely but also make the vapor can flow from the evaporating part to the condensing section.

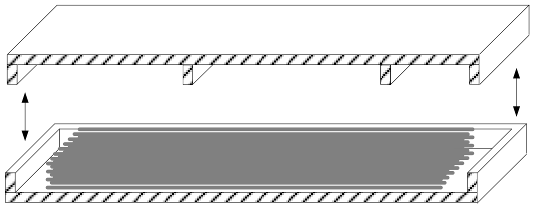

Fig. 1 Structure of the flat micro heat pipe

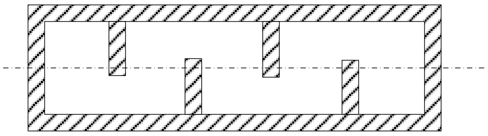

Fig. 2 The shape of the front plate

Mathematical Model

In the calculation process, the vapor flow, the liquid flow and the heat conduction in the solid is regarded. The mathematical model is founded under the following assumptions:

1) The micro heat pipe works in steady state.
2) The vapor and liquid is incompressible.
3) The pressure and temperature of the vapor is homogeneous in the heat pipe.
4) The heat conduction in the liquid along the z direction is neglected.

Based on these assumptions, a three-dimensional mathematical model is founded. In order to formulate the governing equations, the heat pipe is divided into a series of small control volumes of length dz. The schematic diagram of a control volume is shown in Fig. 3.

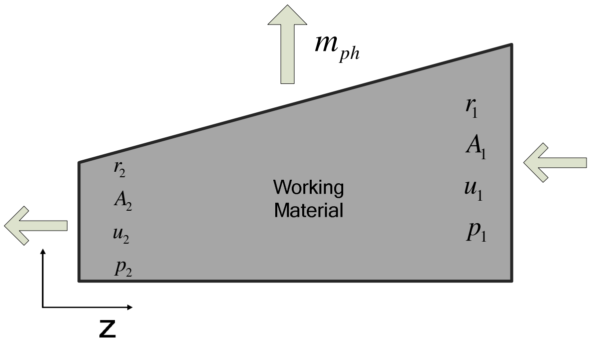

Fig. 3 The schematic of the control volume

In a control volume, the continuity equation for the liquid is expressed as follow:

$$\rho u_1 A_1 + m_{ph} = \rho u_2 A_2 \tag{1}$$

Where u_1, u_2, A_1, A_2, ρ, and m_{ph}, denote the velocity of the liquid flowing into the control volume, the velocity of the liquid flowing out of the control volume, the cross-sectional areas of the analogous triangular, the density of the liquid and the mass of the liquid changing phase on the interface. And mph can be calculated by the energy equation.

For the incompressible flow in the micro heat pipe, Bernoulli equation is used to formulate the governing equations. And in the Bernoulli equations, the flowing resistance and the gravity are regarded and the conservation equation of the axial momentum in the control volume is written as:

$$\frac{p_1}{\rho g} + \frac{u_1^2}{2g} = \frac{p_2}{\rho g} + \frac{u_2^2}{2g} + \frac{u_2^2}{2g} \cdot f + l \sin \varphi \tag{2}$$

$$f = \frac{C_f \cdot l}{D_h} \tag{3}$$

Where P_1, P_2, f, φ, $C_{f,}$ and D_h is the pressure of the liquid in the control volume, friction between the liquid and the channel, the included angle between the micro heat pipe and the horizontal line, friction factor of the flowing liquid and hydraulic diameter of the cross-sectional area of the liquid flow.

The energy equations of the mathematical model are made of two parts. The first part is the phase changing process which occurs on the interface of the liquid and vapor, and the second part is the heat conduction in the wall of the micro heat pipe, between the wall and fiber, and between the fibers.

For the temperature of the liquid is difficult to confirm and the distance between the fibers is quite short, the temperature is assumed to be the average value of the temperature of the two adjacent fibers, which is written as follow and shown in Fig. 4.

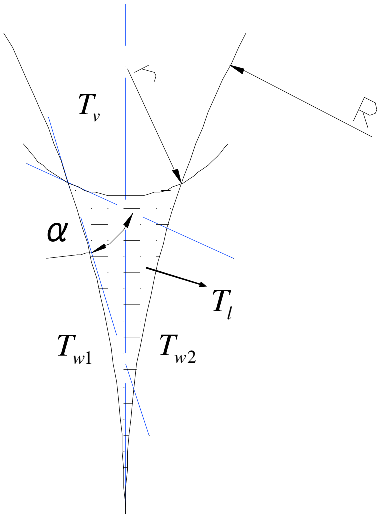

Fig. 4 Temperature of the working material

$$T_l = (T_{w1} + T_{w2})/2 \tag{4}$$

The temperature of interface between liquid and vapor is expressed below:

$$T_{iv} = T_v\left(1 + \frac{P_c}{h_{fg}\rho_l}\right), \quad P_c = \frac{\sigma}{r} \tag{5}$$

So the density of the heat flow on the interface is written as follow:

$$q_{flus} = \frac{T_l - T_{iv}}{R_i}; \quad R_i = \frac{T_v\sqrt{2\pi\delta T_v}}{2h_{fg}^2\rho_v} \tag{6}$$

Where h_{fg}, ρ_l, ρ_v, δ and σ are the latent heat of vaporization, the density of the liquid, the density of the vapor, gas constant, and the surface tension.

The heat conduction in the solid is described by the energy conversation equations for three kinds of nodes, which is shown in Fig. 5. For different kind of nodes different equations is formulated to calculate the heat conduction. In order to distinguish the different node, the three kinds of nodes are numbered by the following rules: Num=4n-1, where n is the number of the fiber levels. The number along the z direction is 1-m, where m is the number of the meshing point along z axis. The governing equations are written as follow:

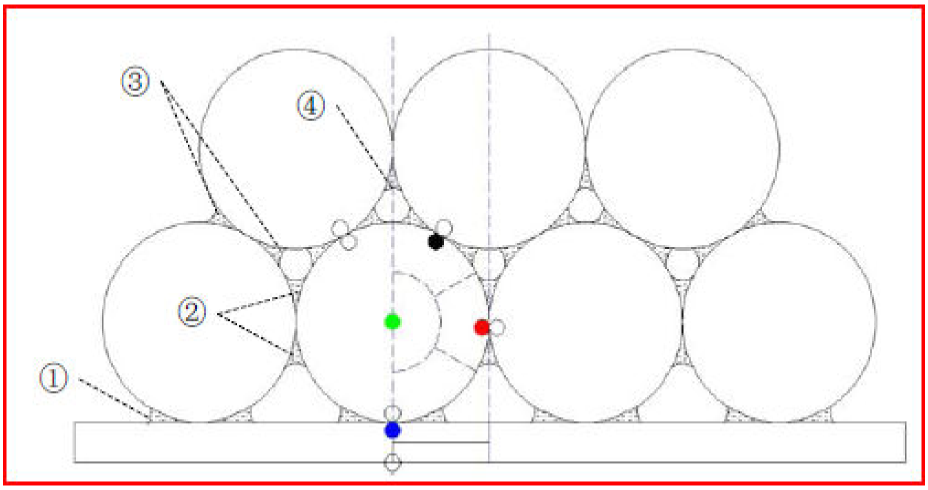

Fig. 5 Three kinds of nodes in the solid

For the first kind of nodes, which is in the wall of the micro heat pipe and is shown in Fig. 5 in blue, the governing equation is written as:

$$\frac{1}{2}\lambda_m dR(T_{2,i-1}-T_{2,i})/dz+2\lambda_m R(T_{1,i}-T_{2,i})dz/d=\frac{1}{2}\lambda_m dR(T_{2,i}-T_{2,i+1})/dz$$
$$+\lambda_{mf}(T_{2,i}-T_{3,i})dz+\frac{1}{2}q_{flux}A_{iv} \tag{7}$$

For the second kind of nodes, which is shown in Fig. 5 in red, the governing equation is written as:

$$\frac{\pi R^2}{8dz}\lambda_m(T_{4n,i-1}-T_{4n,i})+\lambda_m\frac{dz}{2}(T_{4n-1,i}-T_{4n,i})+\lambda_m\frac{\pi dz}{12}(T_{4n+1,i}-T_{4n,i})+$$
$$\lambda_m\frac{dz}{2}(T_{4n+2,i}-T_{4n,i})=\frac{\pi R^2}{8dz}\lambda_m(T_{4n,i}-T_{4n,i+1})+\frac{1}{2}q_{flux1}A_{iv1}+\frac{1}{2}q_{flux2}A_{iv2} \tag{8}$$

For the third kind of nodes, which is shown in Fig. 5 in green, the governing equation is written as:

$$T_{4n-1,i}+T_{4n,i}+T_{4n+1,i}=3T_{4n+1,i} \tag{9}$$

These governing equations make up of the main part of the mathematical model, and the mathematical model can be calculated by iteration in computer program.

Results and Discussion

In order to analyze the working process of the micro heat pipe and optimize the structure of the micro heat pipe, the velocity of the liquid flow along the micro heat pipe is calculated through the mathematical model which is shown in Fig. 6. And the phase changing rate of the liquid is also calculated in Fig. 7. The liquid flow in the micro heat pipe is divided into several levels which are shown in Fig.13. The channel between the fiber and the wall of the micro heat pipe is the first level which is marked as ①, and level ②, level ③, level ④… are indicated clearly in Fig. 5. It can be seen from the calculation results that the liquid in level ① transports heat the most efficiently, because the velocity of the liquid in level ① is the biggest in adiabatic section and the phase changing rate of the liquid in level ① is the most prominent. For the micro heat pipe, the heat conducting effect of the liquid in level ② and level ③ is smaller and smaller. The liquid in level ④ almost does not work, and the velocity and the phase changing rate are all nearly zero.

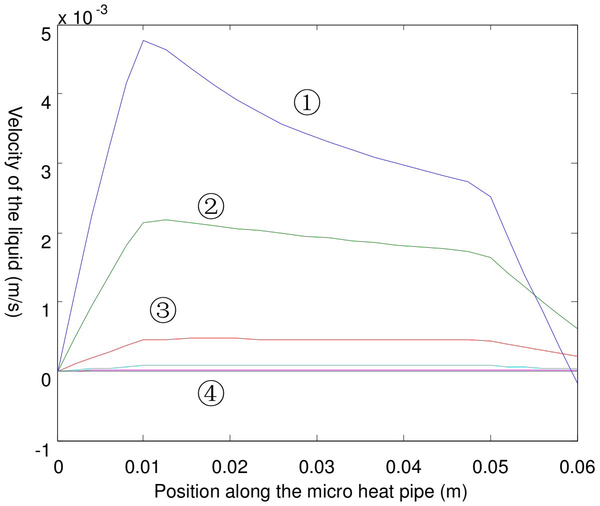

Fig. 6 The velocity of the liquid

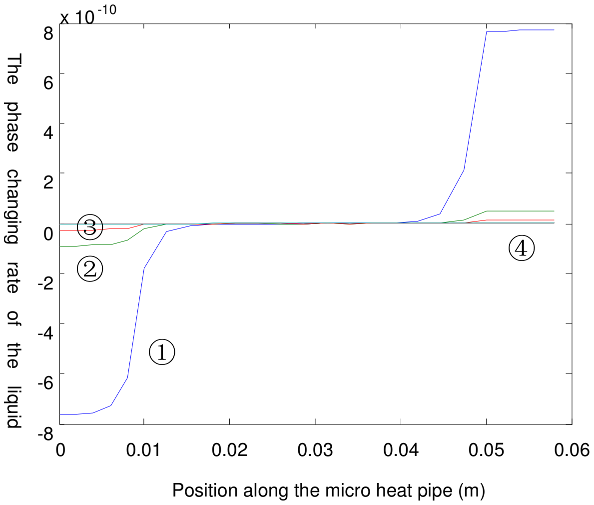

Fig. 7 The phase changing rate of the liquid

So the calculation results show that the liquid which is adjacent to the heat pot works better, because the thermal resistance between the fiber and the wall of the micro heat pipe stops the liquid in level ④ to absorb heat and to change phase. So two levels of fibers in the micro heat pipe are enough, and it is unnecessary to fill in more fibers.

Conclusions

A mathematical model is developed for accurately predicting the thermal performance of a flat micro heat pipe with fiber wick and optimizing the structure. The effects of the phase changing, heat conduction in solid, and contact thermal resistance have been included in the present model. The governing equations are formulated by conservation of mass, momentum and energy in three dimensions. The model is calculated by iteration and the results show that the first and second level of the fibers in the micro heat pipe is efficient and the third level is unnecessary.

References

[1] B. Suman, S. De. Transient Modeling of Micro Grooved Heat Pipe. International Journal of Heat and Mass Transfer. vol. 48, 2005 pp. 1633-1646

[2] G. Pandraud, L. B. Martine. Influence of the Fluid on the Experimental Performances of Triangular Silicon Microheat Pipes. Journal of Electronic Packaging. vol. 128, 2006, pp. 294-296

[3] A. J. Jiao, H. B. Ma, J. K. Critser. Evaporation Heat Transfer Characteristics of a Grooved Heat Pipe with Micro-Trapezoidal Grooves. International Journal of Heat and Mass Transfer. vol.50, 2007, pp. 2905-2911

[4] B. Suman, N. Hoda. Effect of Variations in Thermophysical Properties and Design Parameters on the Performance of a V-shaped Micro Grooved Heat Pipe. Journal of Heat and Mass Transfer. vol.48, 2005, pp.2090-2101

[5] Liu Xiaowei, Xin Xin, Huo Mingxue, Xu Lei. Thermal analysis and maximum heat transport of a micro flat heat pipe with axial triangle grooves. Chinese Journal of Sensors and Actuators. vol. 9, 2007, pp. 2103-2107

[6] G. P. Peterson, H. B. Ma. Theoretical Analysis of the Maximum Heat Transport in Triangular Grooves: A Study of Idealized Micro Heat Pipes. Journal of Heat Transfer. vol.118, 1996, pp. 731-739

[7] Balram Suman, Prabhat Kumar. An analytical model for fluid flow and heat transfer in a micro-heat pipe of polygonal shape. International Journal of Heat and mass Transfer. vol.48, 2005, pp. 4498-4509