Pumping Mechanism of Thermally Driven Phase Transformation Type Micropump[*]

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Abstract

Micro fluidic system is one of the most important ramifications of MEMS. Micropump, as an executive device, plays an important role in a practical micro fluidic system. It can be used in many application fields, such as fluid distribution, chemical analysis, environment checking, micro injecting and medical transportation, micro cooling of electronic components, etc..

Micropump can be divided into two types: pumps with mechanical moving parts and pumps without mechanical moving parts. The micropump with mechanical moving parts is easily to be controlled and independent on the characteristics of the fluids. Nevertheless, the size of the pump is limited by the dimension of the actuators and the manufacture is more complicated. Therefore, the micropumps without mechanical moving parts have been paid more attention and a lot of new micropumps were developed, such as thermopneumatic micropump[1], electrohydrodynamic(EHD) micropump[2], magneto-hydrodynamic(MHD) micropump[3], ion-drag micropump[4] and phase transformation type micropump[5,6], etc.

Fig. 1 shows the structure of a phase transformation type micropump which consists of a micro tube (or channel) and an array of heating elements. By scanning electric current supplied through the heaters with different phases cyclically, the liquid in the channel is evaporated in the heating section and pumped toward the scanning direction. Apparently, it has no mechanical moving parts, and therefore is easy to fabricate and suitable for micromation.

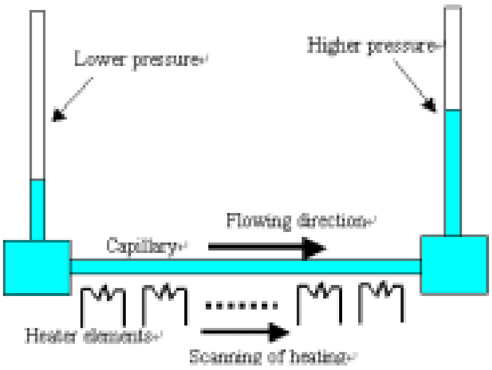

Figure 1. Structure of phase transformation type micro pump

Ozaki[5,6] et.al. first did research on this kind of micropump. In their theoretical analysis, they assumed that three parts of the fluid (liquid, gas and liquid) flow in the channel time-independently. The two-phase region was ignored. Then they drew a conclusion that the pumping mechanism was the large difference of the kinematic viscosity between liquid and gas.

This paper presents the newest theoretical and experimental results on the pumping mechanism of the phase transformation type micropump. To study the pumping mechanism, a single phase tube flow with moving heat sources was firstly investigated. Fig. 2 shows the physical model. The working fluid is air. The heat sources move at a speed of U. Fig. 3 shows the numerical results of the density and velocity of the gas at x=0 varying with time within a cycle. Fig. 3 indicates that the mass transported towards the positive x direction is more than that

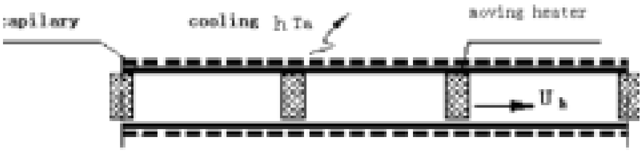

Figure 2 Single phase tube flow with moving heat sources

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towards the negative x direction. That is to say, a mass flow toward the moving direction of the heat sources is achieved.

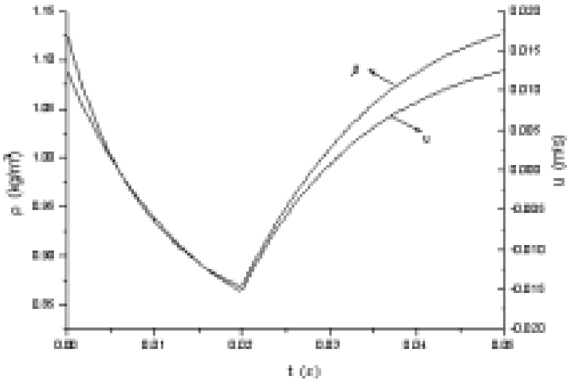

Figure 3 The density and the velocity of the gas varying with the time

Based on the analysis of the single phase tube flow mentioned above, a simplified model of the phase transformation type micropump is established shown in Fig. 4. The total length of the microtube is L. The heat source moves at a speed of U_h, L_l, L_t, and L_g are the the lengths of the liquid section, two phase section and gas section respectively. Define the subscript “m” as the averaged value over the whole channel, we can obtain the following equations:

$$\rho_m = \left(\int_0^L \rho dX \right) \Big/ L \qquad (1)$$

$$\mu_m = \left(\int_0^L \mu dX \right) \Big/ L \qquad (2)$$

$$\nu_m = \left[\int_0^L (\mu / \rho) dX \right] \Big/ L \qquad (3)$$

Fig.5 shows the numerical results of the relations of $\rho_m - \mu_m / \nu_m$ and L_l / L_t when L_v / L_t is constant.

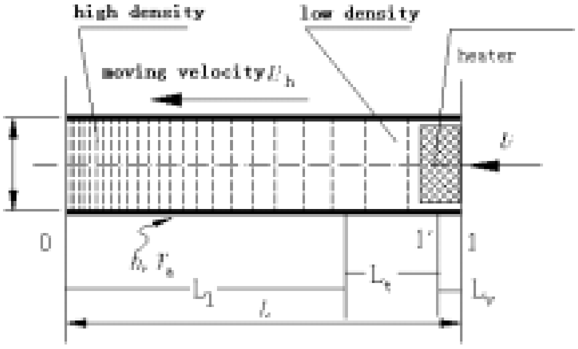

Figure 4 Physical model of the micropump

By defining a characteristic flow rate as follow,

$$m_0 = \frac{4h(T_s - T_0)L}{Dr} \qquad (4)$$

where D is the diameter of the microtube, h is the heat transfer coefficient, r is the latent heat, the mass flow rate of the micropump can be expressed as:

$$m = \frac{\Delta p D^2 \rho_m}{32 L \mu_m} + m_0 \cdot \frac{L_t}{L \Delta \phi} \left(\frac{\rho_m \nu_m}{\mu_m} - 1 \right) \qquad (5)$$

where Δp is the pressure drop between inlet and outlet, $\Delta \phi$ is the possible quality variation.

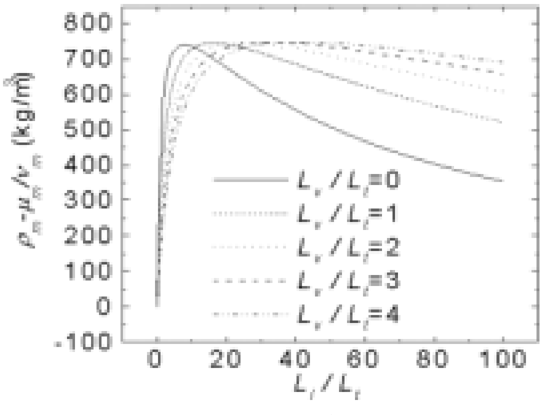

Figure 5 Relations of $\rho_m - \mu_m / \nu_m$ and L_l, L_t, L_v

The maximum pumping flow rate is expressed as,

$$m_{\max} = m_0 \eta_f \qquad (6)$$

where η_f is the coefficient of flow rate which is expressed as

$$\eta_f = \frac{L_t}{L\Delta\phi}\left(\frac{\rho_m v_m}{\mu_m} - 1\right) \qquad (7)$$

Fig. 6 shows the η_f versus L_l / L_t for different L_v / L_t. It is clear seen that there exists an optimal L_l/L_t with which the flow rate reaches maximum.

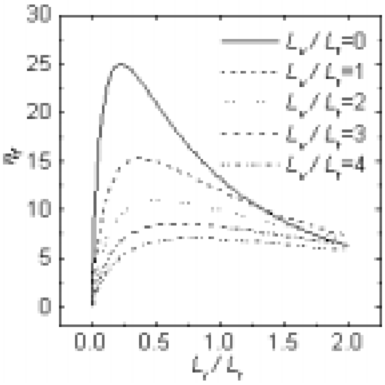

Figure 6 Relations of η_f and L_l, L_t, L_v

An experimental study on the micropump is also performed in this paper. In the experiments, the inner diameter of the microtube is 200μm, the fluid is distilled water. Fig. 7 shows the experimental results of the flow rate. It is seen from Fig.7 that there is an optimal heating current for a given cooling condition and a given micropump. It is somewhat similar to the theoretical analysis.

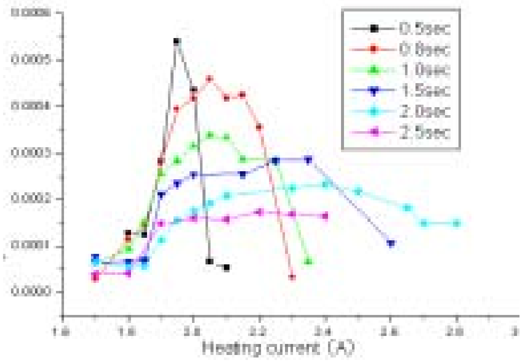

Figure 7 Flow rate curves from the experiment

Based on the theoretical and experimental results, it is concluded that the pumping mechanism of the phase transformation type micropump is the variety of the properties of the fluid resulted from evaporation and condensation. The two phase section in the microtube plays a very important role in improving the pumping ability. And a reasonable coordination of the heating condition, cooling condition and the moving speed of the heat source will lead to the maximum flow rate.

Reference

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