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# A MICRO DIFFUSER/NOZZLE PUMP WITH FINS ON THE SIDEWALL

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**Abstract:** As the diffuser/nozzles are the key parts for micro diffuser/nozzle pumps, this paper reports a novel method for improving the flow efficiency by adding fins on its sidewall. The shape of the fin is imitative of the fish fins. Hence some fins fabricated through silicon micro-machining technology are integrated with the nozzle/diffusers. It has been testified that the big fins can improve the flow efficiency by 10 percent both for liquid and gas, which indicated that the corresponding pump performance would be improved by 20 percent. An excellent liquid pump performance is also gained in this paper.

**Keywords:** Diffuser/nozzle; Fins; Flow efficiency; Diffuser/nozzle pump;

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## 1. INTRODUCTION

Major advantages of micro diffuser/nozzle pump are that the risk of wear and fatigue in passive check valves is eliminated and that the danger of valve clogging is reduced [1]. As diffuser/nozzles are the key parts, many research jobs have been focused on optimizing its physical dimension [2, 3] and developing micro fabrication technology [4] for µTAS application.

Our approach is to improve the rectification characteristic for the diffuser/nozzle by adding fins on its sidewall. The initial idea was come from the fish fins. When the fish goes forward in the water, whose fins bring less resistance, but more resistance when the water flow backward through them. Therefore, some imitated fins fabricated through silicon micro-machining technology are integrated on the sidewall of the nozzle/diffusers. It has been testified that the big fins can improve the flow efficiency by 10 percent both for liquid and gas, which means the corresponding pump performance can be improved by 20 percent.

## 2. THEORY AND DESIGN

2.1 Diffuser/nozzle with fins

A diffuser is a conduit with an expanding cross-sectional area in the flow direction intended to reduce velocity in order to recover the pressure head of the flow, while a nozzle is that with decreasing cross sectional area in the flow direction. A diffuser/nozzle can be divided into three different regions, as illustrated in Fig.1

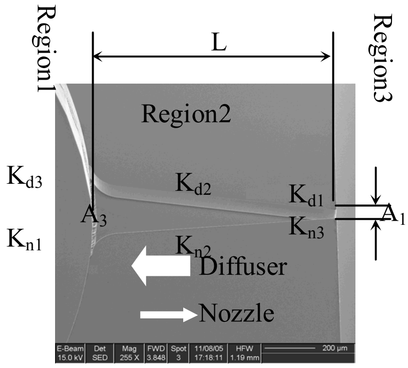


*Fig. 1 SEM of micro diffuser/nozzle with flat wall, the diffuser/nozzle is divided into three regions. (top view)*

The flow efficiency η for diffuser/nozzle can be expressed as [5]:

$$\eta = \frac{K_{nozzle}}{K_{diff}} = \frac{K_{n1} + (K_{n2} + K_{n3})(A_1/A_3)^2}{K_{d1} + K_{d2} + K_{d3}(A_1/A_3)^2} \qquad (1)$$

Where $K$ is the pressure loss coefficient for different region, $A_1$ and $A_3$ are the cross-sectional area at region 1 and 3 according to Fig.1. The ratio $\eta$ for diffuser/nozzle element has to be greater than one in a diffuser pump. It means that the pressure loss for a given flow in the diffuser direction is lower than that in the nozzle direction,

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while $\eta<1$ will lead to pumping action in the nozzle direction. Geometric configuration and calculated $\eta$ of the test diffuser/nozzle according to Fig. 1 were shown in table 1.

*Table 1 Geometric configuration of the test diffuser/nozzle according to Fig. 1*

| Throat width W [μm] | Diffuser length L [μm] | Diffuser Angle θ | Deepness [μm] |
|---|---|---|---|
| 40 | 1000 | 14° | 80 |
| Shape of cross-section | Area ratio ($A_1/A_3$) | η (theory) | |
| Rectangle | 0.14 | 1.77 | |

During one actuation period T, the average volume output flow rate ($Q$) of the pump can be expressed as [5]:

$$Q = \frac{2\Delta V_m}{T}\frac{\sqrt{\eta}-1}{\sqrt{\eta}+1} \quad (2)$$

Here $K_n$ and $K_d$ is the pressure-loss coefficient of nozzle and diffuser respectively, $\Delta V_m$ is the volume variation of the pump chamber. The flow efficiency ratio $\eta$ is defined as $K_n / K_d$. The relationship between $Q$ and $\eta$ was indicated in equation (2). If $\eta>1$, then $Q>0$, the fluid will enter the pump cavity from the inlet and pump out from the outlet, hence the net flow is formed from inlet to outlet.

As we all known that fish fins bring less resistance when the fish goes forward in the water, but more resistance when the water flow backward through them. Therefore imitated fish fins fabricated through silicon micromachining were added on the sidewall of the diffuser/nozzle. Big and small fins (less than 20μm) were designed for comparing. Figure 2 and 3 is the SEM for the diffuser/nozzle with big fins and small fins on its sidewall.

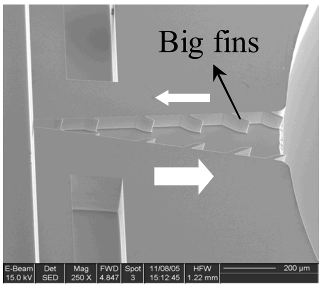


*Fig. 2 SEM of Micro diffuser/nozzle with big fins on its sidewall. (top view)*

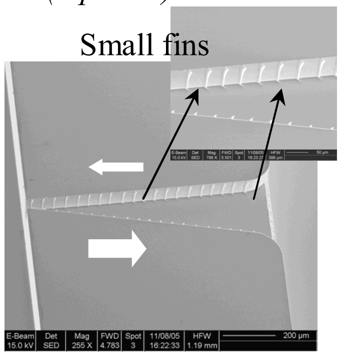


*Fig. 3 SEM of Micro diffuser/nozzle with small fins on its sidewall. (top view)*

2.2 Micro diffuser/nozzle pump

The diffuser/nozzle pump was fabricated through silicon micromachining processes combining with double layer mask technology. Two steps of deep reactive ion etching were carried out to form the pump chambers with the diameter of 5mm and two diffuser/nozzles individually. Then the silicon wafers were anodic bonded to a glass wafer. At last the inlet and outlet hole were etched on the backside of the silicon wafer. A piezo-disk was used as an actuator for the micro pump. The optical image and the cross section of the micro pump were shown in Fig. 4.

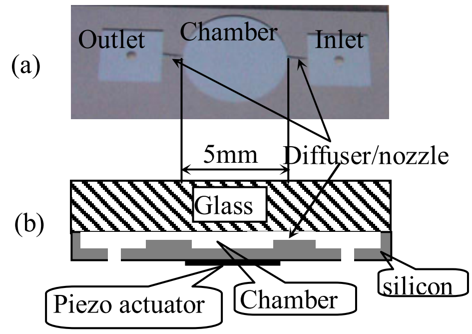


*Fig. 4 optical image and cross section of the micro diffuser/nozzle pump*

## 3. MEASUREMENT RESULTS AND DISSCUSSION

3.1 Results for micro diffuser/nozzle

The stationary flow measurements [6] were performed on the above three diffuser/nozzles. The simplified diagram of the measurement apparatus was built up as shown in Fig. 5. The



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experimental setup includes the pressure source, the testing section and the flow rate measuring section. The testing section consisted of a pressure transducer that is connected to the inlet of the micro-unit, through which the inlet pressure of the micro-unit could be measured. At the end, the outlet was linked to a horizontal setting pipette with water in it. The gas volume flow was obtained by measuring the volume change of water forced out by the working gas through electronic balance. The mass flow rate of the liquid through the micro-unit could be gained directly by measuring the weight of the effluent liquid.

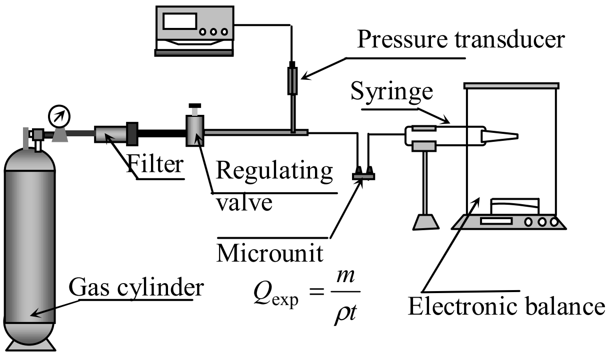


*Fig. 5 A simplified diagram of the Stationary flow measurement setup.*

The static flow measuring results using gas and liquid as the actuation fluid were shown in Fig. 6 and 7. As can be seen the small fins don't interfere the fluid flow which only change the roughness of the sidewall, so the diffuser/nozzle with flat wall and with small fins had equal flow efficiency in the measurement range. The diffuser/nozzle with big fins gained higher flow efficiency than the others both under gas and liquid actuation. The flow efficiency differences were abnormal at the pressure below 15kPa which should be removed. The average measured flow efficiency both for liquid and gas as working fluid was shown in table 2. It was indicated that flow efficiency for diffuser/nozzle with big fins is 10 percent greater than that for the flat wall. Liquid has better rectifying action than gas for its higher viscosity.

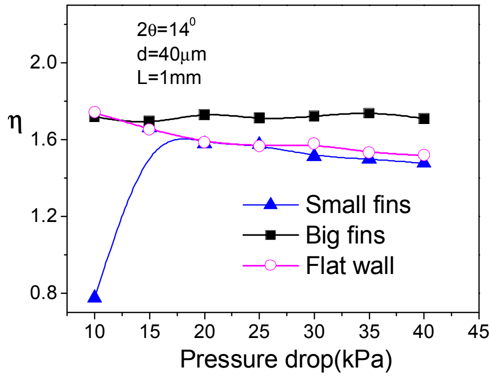


*Fig. 6 Flow efficiency $\eta$ comparing results for the diffuser/nozzles with and without fins in liquid.*

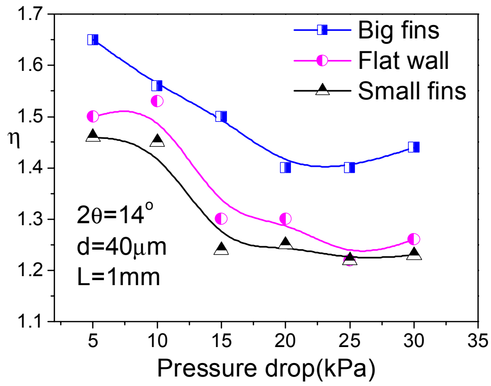


*Fig. 7 Flow efficiency $\eta$ comparing results for the diffuser/nozzles with and without fins in gas.*

*Table 2 Experimental average flow efficiency for the diffuser/nozzles.*

| | Flat wall | Big fins | Increase |
|---|---|---|---|
| Gas:η | 1.33 | 1.44 | 11% |
| Liquid:η | 1.55 | 1.72 | 10% |
| Increase | 17% | 19% | |

3.2 Results for corresponding micro pump

The characteristics measurements on micro diffuser/nozzle pump were performed by piezoelectric actuation. . The measuring results between the diffuser/nozzle pump output flow rate and the driven voltages at the frequency of 3kHz was shown in Fig. 8. The volume flow rate increased almost linearly with the driven voltage. The pump began to work at the voltage of 20V. Figure 9 was the relationship between the diffuser/nozzle pump output flow rate and the driven frequencies at the voltage of 100V. It can be found that there was a peak at 3.4kHz. Hence the best pump working frequency is 3.4kHz.



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Figure 10 showed the pressure head increased linearly with the driven voltage at the frequency of 3.4kHz. The micro pump with fins could achieve the pressure head of 35cm water column at the frequency of 3.4kHz and the driven voltage of 60V.

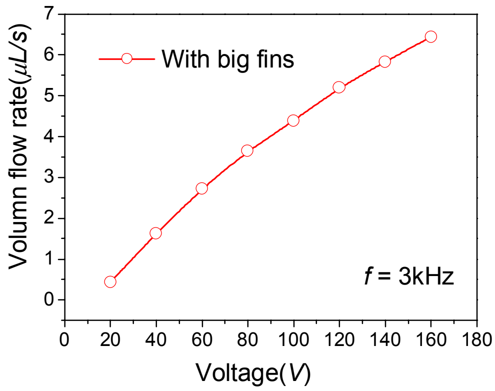


*Fig. 8 The relationship between the diffuser/nozzle pump output flow rate versus driven voltage at the frequency of 3kHz.*

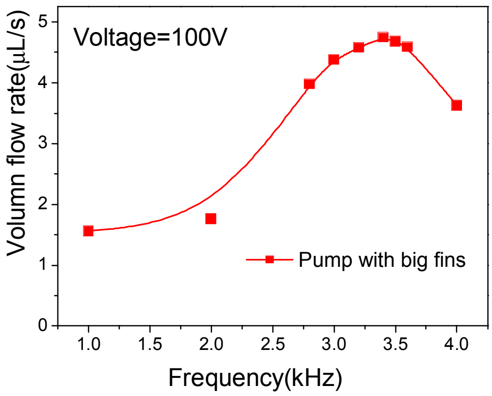


*Fig. 9 The relationship between the diffuser/nozzle pump output flow rate versus the frequency at the voltage of 100V.*

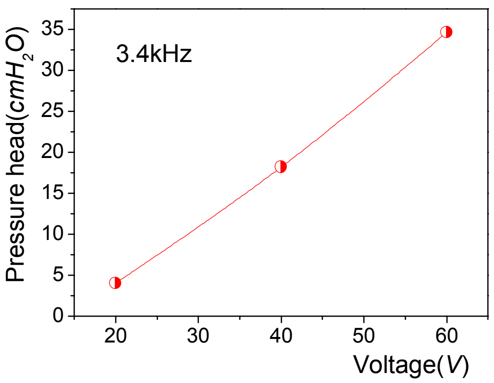


*Fig. 10 The relationship between the pressure head and the driven voltage for micro diffuser/nozzle pump with big fins on its sidewall at the frequency of 3.4kHz.*

## 4. CONCLUSION

A novel method by using fins to improve the flow efficiency for diffuser/nozzles was put forward in this paper. The flow efficiency for the diffuser/nozzle with big fins can be improved by 10 percent comparing to that with flat wall. It means that the corresponding pump performance can be increased by 20 percent. Because of its simple fabrication process, polymers are also the promising material for the diffuser/nozzle pump with fins.

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