NOZZLE-DIFFUSER BASED MICRO BUBBLE PUMP

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ABSTRACT

A valve-less micropump is demonstrated by utilizing thermal bubbles as the actuation mechanism and a nozzle-diffuser pair as the flow controller. The pump consists of a single resistive heater, a pair of nozzle-diffuser flow controller, and a 1 mm in diameter, 45 μm in depth pumping chamber. Liquid is pumped by generating and collapsing of thermal bubbles via resistive heating. A maximum flow rate of 5 $\mu\text{l}/\text{min}$ is measured at the driving voltage of 20V with 10% in duty at 250Hz of pulsed power supply.

INTRODUCTION

Micro pumps have wide applications for handling small and precise fluid volumes on chemical, medical, and biomedical devices. Various types of micro pumps have been proposed and demonstrated over the last decade. They can be classified into following types based on the actuation mechanisms: mechanical displacement [1-3], bubble [4], electrohydrodynamic [5], and electrocapillarity [6] pumps. Among them, bubble pumps are less limited by the geometry and size than rotary and diaphragm pumps, also less constrained by the fluid type than electrohydrodynamic and electrocapillarity pumps.

One the other hand, micro valve has been a significant issue in all micropumps because of the relatively high leakage rate [7-10]. Previously, a valve-less pump has been demonstrated with a nozzle-diffuser type flow controller [4] and a diaphragm shape piezoelectric actuator as the pumping mechanism. In this work, instead, bubbles function as a membrane in a diaphragm typed positive displacement pump. Together with the nozzle-diffuser design, this new pump provides advantages of flexible membrane, less dead volume in the pumping chamber and valve-less pumping.

Fig. 1, Schematic drawing of the nozzle-diffuser based bubble pump.

DEVICE FABRICATION

The micropump is schematically drawn in Fig. 1. All the pumping chamber, nozzle-diffuser and channels are fabricated on a silicon substrate at the same depth of 45 μm . The meander aluminum heater on a Pyrex glass wafer is 10 μm in width and 1 μm in thickness. The circular pumping chamber is 1mm in diameter and is connected with a pair of nozzle-diffuser flow controller of 30 μm in the narrow neck, 274 μm in the open mouth and 7° in the diverge angle. The fluid channel is 200 μm in width. Liquid and electricity connections are constructed by through holes on the silicon substrate. Figure 2 shows the simplified fabrication process flow and the fabricated device. On the silicon substrate, the surface is firstly grown a 1 μm thick silicon dioxide layer, patterned and etched as the mask of pumping chamber, nozzle-diffuser and channels. A 9 μm thick photoresist is spun on, patterned and etched by DRIE to open the liquid and electricity interconnection through holes. Afterwards, the photoresist is removed and the silicon wafer is put into DRIE etcher again to define the pumping chamber, valves and channels. After these steps, the silicon wafer is dipped into hydrofluoric acid (HF) to remove silicon dioxide. On the Pyrex glass, the wafer is patterned and etched in buffered HF to form shallow trenches for embedding the aluminum heater for the anodic bonding process. The aluminum layer is then evaporated and patterned by the lift-off process. The silicon and Pyrex wafers are finally aligned and anodically bonded at 380°C.

Fig. 2, (a) Simplified fabrication process flow. (b) Optical photograph of the fabricated micropump.

EXPERIMENTS

The pumping flow rate is measured under the same inlet and outlet static pressures. For flow rate measurement, the fabricated micro pump is connected from the inlet and outlet holes to two polyimide tubes of 310 μ m in outer diameter and 275 μ m in inner diameter. The far ends of the tubes are then connected to syringes filled with liquid as liquid reservoirs. Once the equilibrium state is reached, the pumping flow rate is measured from the averaged speed of the air slug in the tubes.

Figure 3 shows the measured flow rates at three different pulse duties, 5%, 10% and 15%, under pulse voltage of 20 volts. It is found that the maximum pumping rate is 5 μ l/min when the pulse duty is at 10% and the pulse frequency at 250Hz. The pumping effect seems to diminish when pulse frequency is higher than 500Hz. The experiments of pumping rate with respect to pulse width have also been conducted as shown in Fig. 4. The maximum flow rates are found around the pulse width of 0.4 milliseconds at each pulse duties. In experiments, pumping chamber may saturate with gas if the pulse frequencies are outside the peak flow rate region. This gas saturation phenomenon is caused by improper ratio of heating to cooling cycles. Heat residual accumulates on the Pyrex substrate such that generated bubbles cannot condense back to liquid. Consequently, the oscillatory membrane-like pumping effect decreases. On the other hand, if two sequential heating periods are too close, the bubble has no sufficient time to collapse thoroughly. Once the pumping chamber is filled with bubbles, the pumping effect diminishes.

SUMMARY

In the paper, a micro nozzle-diffuser based bubble pump driven by pulse is demonstrated. The pumping volume flow rate is in the order few μ l/min. Pulse duty control method is found more effective on the volume flow rate than the pulse frequency control method. Maximum volume flow rate at 5 μ l/min is measured under the conditions of pulse duty at 10% and pulse frequency at 250Hz.

FUTURE WORKS

Although gas saturation can totally hinder the pumping effect, it can be improved and may be prevented by better thermal

Fig. 3, Volume flow rate measured under the same inlet and outlet static pressure at pulse voltage of 20V.

Fig. 4, Volume flow rate versus pulse width at pulse voltage of 20V.

management, such as operating the heater at higher temperature to generate more consistent bubbles, shortening the heating time to prevent heat accumulation on the Pyrex substrate, and widening the heater to generate larger bubble in shorter time. Once the thermal management is improved, the nozzle-diffuser based bubble pump can operate in a more efficient way.

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