Electrolysis-Bubble-Actuated Micropump

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Abstract—An electrolysis-bubble-actuated micro pump is created. The pump is created with a top surface gradient across the channel. This changing gradient will help to propel the bubble, created by electrolysis, forward. This micropump is implemented by taking advantage of both surface tension effect and the electrolysis actuation. The surface tension effect is controlled via the periodic generation of electrolytic bubbles and the roughness gradient design of the microchannel surface. The fabrication of the device was completed following the processes outlined in the design phase. Adhesion problems between the top surface and the silicon substrate were encountered during testing. As result, new layer for better adhesion needs to be implemented in future designs.

Index Terms—Bubble, electrolysis, microelectromechanical systems (MEMS) micropump, roughness gradient, surface tension.

I. INTRODUCTION

MICROPUMPS have been the subject of extensive research in both academia and the private sector. In addition, they have been produced in variety of designs that use different actuation mechanisms. Diaphragm micropumps [1] for example, achieve a high volume through a large chamber by using a membrane: however, most techniques for fabricating such diaphragm-based pumps are complicated and involve many photolithographic steps. Another technique [2, 3] drives fluid by applying a high voltage to it. Among such approaches, bubble-actuated valveless micropumps are attractive for their simple operation, miniaturized size, large actuation force, and the ability to physically comply to different types of microchannels with a wide range of cross-sections. Although demonstrated successfully in [4-6], these valveless pumps require a complex time-sequenced power control on many electrodes pairs and a large or long nozzle-diffuser structure. Moreover, further disadvantages include the need for a sealed reservoir inside the fluidic chip.

To overcome the problems presented by other pumps, the top surface of this micropump will have a simple patterned surface with different roughness across in order to propel the bubble that is created forward. This micropump is implemented by taking advantage of both surface tension effect and the electrolysis actuation. The surface tension effect is controlled via the periodic generation of electrolytic bubbles and the roughness gradient design of the microchannel surface.

Compared with other actuation mechanisms, the electrolysis bubble actuator has the features of simple structure, low-power consumption, room temperature operation, and being easy to be integrated into a lab chip. The advantage of this design is the low power consumption and room temperature operation.

II. DEVICE OPERATION PRINCIPLE AND MICROFABRICATION PROCESS

A. Operation Principle

Figure 1 illustrates the design concept. The device consists of polysilicon electrodes, a hydrophilic microchannel, and a hydrophobic lateral breather connected to air for the elimination of bubbles. The pumping principle—shown schematically from the side in Figure 1(b)—relies on surface tension and multiple bubble-actuation cycles. The actuation mechanism is divided into three phases: bubble generation, degassing, and liquid movement. First, the bubble is generated by electrolysis to push the liquid in whichever direction is required. Next, the bubble is vented out through the lateral breather. At the sides of the microchannel, surface tension exerts a pull on the liquid that creates a characteristic concave shape called a meniscus. Due to the roughness gradient design, the apparent contact angle of the leading meniscus (right) is larger than that of the trailing meniscus (left): \( \theta_L > \theta_R > 90^\circ \).

Thus, the pressure on the left is larger than that on the right: \( P_L > P_R \). As a result, the menisci respond with different velocities, and a net pumping flow along the \( x \) direction is achieved. Displacement of the liquid occurs through repetition of these cycles.
Thenetvolumedisplacementofliquidandthepumpingratearedominatedbythegeometrydesign
ofthemicrochannel,thedesignoftheroughness
gradientsurface,thefrequencyandamplitudeofthe
appliedvoltage,andthedesignoftheelectrodes.All
detailswillbedescribedwiththeexperimental
resultslaterinthispaper.

B. Microfabrication

The microfabrication process for our micropump
isillustratedinFig.1(a).First,astandardn-type100
siliconsubstrateisgrownwiththethermaloxideof
500Å. Then1500Å of Silicongrit are deposit.
Theseare lithographicallypatterned with the
channel. Then, the substrate is etched by the wet
etchingprocessinKOHsolutiontodefinedethe
microchannel. A BOE etch of one minute is
perform to remove the 500Å of oxide. Then the
substrate is grown with another 6500Å thermal
oxide. This thermal oxide is only deposit in the
channel surface to form the hydrophilic layer. The
Silicon nitride is then removed so the silicon
substrate is the exposed. Poly silicon is deposit,
6000Å for the formation of the electrodes. Next,
Positive photoresist is spin coated on the wafer and
cured at in a high-temperature oven. The photoresist
is lithographicallypatterned and etched as
hydrophobicregions by the O2 plasma process to
serve as the bottom part of the hydrophobic lateral
breather. The top cover with the roughness gradient
structure is fabricated by using a dry film negative
photoresist. A first layer is exposed first and then a
second layer with the pattern is mounted.
The structural design of the surface roughness gradient in our device is illustrated in Figure 3. The surface roughness varies with the pillar patterns on the dry film resist cover. For our roughness gradient design, pillar decreases along the x-direction of the microchannel.

![Decreasing gradient](image)

Fig. 3. Illustration of the roughness gradient design on the hydrophobic surface of the top dry film resist cover that is made of square pillars.

The roughness gradient surface of our micropump is hydrophobic, which leads to the formation of a composite surface. Besides, previous report from Shirtcliffe et al. has also shown that the dimension variation of square pillars allows the length of the contact perimeter per unit area to be varied without varying the contact area per unit area [30]. As a result, there is no change on the contact angles.

**B. Electrolysis**

When an electric current is sent through the two noble metal electrodes (such as platinum) in water, electrolysis takes place. The minimum equilibrium potential of hydrogen–oxygen electrolysis $E^\circ$ is 1.23 V. In the electrolysis reaction, the oxygen gas is produced at the anode, and the hydrogen gas is produced at the cathode, i.e.

**anode**: $2H_2O \rightarrow 4H^+ + 4e^- + O_2$

**cathode**: $2H_2O + 2e^- \rightarrow 2OH^- + H_2$

Under the assumption that all generated gases ($O_2$ and $H_2$) evolve in the form of gas bubbles, the total gas volume linearly depends on the input electrical charge [17]. The total gas volume generated by the electrolysis in the process of bubble nucleation could be estimated according to Faraday's law of electrolysis and the ideal gas law [31].

$$N = \frac{It}{zF}$$

$$PV = NRT$$

where $N$ is the moles of produced gas, $I$ is the applied current, $z$ is the number of excess electrons, $F$ is Faraday's constant ($9.649 \times 10^4$ C/mol), $t$ is the period of electrolysis, $T$ is temperature, $P$ is the ambient pressure, $V$ is the volume of the bubble, and $R$ is the gas constant ($8.314 \text{ J K}^{-1}\text{ mol}^{-1}$). Under the assumption of constant temperature and atmospheric pressure, the volume of produced gases is proportional to the supplied electric current [32].

**D. Applied Voltage**

The pumping flow rate relies on many factors, such as the applied voltage, the duty cycle, and the driving frequency. These imply that the actuation pulses play a dominant role for the maximum pumping flow rate. Besides, the expansion period and the venting period of the bubble in one pumping cycle are also critical parameters to regulate the square-wave actuation pulses. The operation frequency $f$ and the duty ratio $d$ are defined as

$$f = \frac{1}{t_{\text{expand}} + t_{\text{vent}}}$$

$$d = \frac{t_{\text{expand}}}{t_{\text{expand}} + t_{\text{vent}}}$$

where $t_{\text{expand}}$ and $t_{\text{vent}}$ are the expansion period and the venting period of the electrolytic bubble in one pumping cycle. The expansion period $t_{\text{expand}}$ is dominated by the period of the applied voltage in one pumping cycle. The venting period $t_{\text{vent}}$ is dominated by the bubble volume and the pressure magnitudes on both meniscuses.

**IV. EXPERIMENTAL SETUP**

To characterize the performance of the micropump with different depths were fabricated. The test was done by using low-power oscillators to create the square waveforms required by each poly-electro to generate the bubble.

**V. EXPERIMENTAL RESULTS AND DISCUSSION**
Fig. 6(a) shows a prototype device made of the dry film resist. The fabrication of the device was completed following the processes outlined in the design phase, but adhesion problems between the top layer and the silicon substrate were encountered during testing. This problem made it impossible to acquire data for the characterization of the micropump.

VI. CONCLUSION

A electrolysis-bubble-actuated micropump with the design of the roughness gradient on the microchannel hydrophobic surface and the lateral breather was successfully fabricated. Further work to optimize the adhesion between the dry film resist and the silicon surface is need. The features of micropumps on compact size, simple microfabrication, low-power consumption, and room temperature operation make it promising to be integrated with other multiple components to form microfluidic systems.

REFERENCES