평면형 초소형 전하 주입식 펌프의 제작 및 실험
FABRICATION AND EXPERIMENT
OF PLANAR MICRO ION DRAG PUMP

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ABSTRACT

A micro ion drag pump with planar electrodes on a glass substrate is fabricated and tested. The pump consisted of a 2-dimensional electrode pair array is driven by DC voltage using unipolar conduction. Ethyl alcohol is pumped in both directions, and the flow rate and the pressure are measured, in channels of depth 100 μm or 200 μm and width fixed at 3 mm. It is found that the pump could be fabricated easily and at lower cost than the micro ion drag pumps previously investigated.

Key Words: electrohydrodynamics (정전유체역학), micropump(초소형 펌프), ion drag pump(전하 주입식 펌프)

1. INTRODUCTION

With the development of micromachining technology, intensified research efforts are being directed towards micro fluid systems and micro liquid handling devices [1-4] such as drug delivery systems or micro cooling systems. An electrohydrodynamic (EHD) pump transports a fluid using the interaction between the electric field constructed by an applied voltage and the charges in the fluid. The applied electrical force directly acts on the fluid, so an EHD pump needs no moving parts such as pistons or valves. Simple structure and ease of fabrication are attractions of a micro EHD pump. In addition, high reliability of the pump and non-contamination of fluid can be achieved since the non-mechanical structure prevents the pump from suffering due to wear.

The ion drag pump, one type of EHD pump, has been studied or fabricated by many researchers. Stuetzer [5,6] and Pickard [7,8] studied the mechanism of ion drag pumping analytically and experimented with macromodels driven by high DC voltage in the range of several tens of kilovolts.

A unidirectional micro ion drag pump was fabricated and

experimented by Richter and Sandmaier[2,3]. They used silicon anisotropic etching to make a three-dimensional micromachined ion drag pump with spacing of emitter and collector decreased to 10~50 μm, where the operating voltage was lowered under 1 kV.

All conventional ion drag pumps, both macromodels and micromodels, have the flow direction fixed by the pump's structure or electrode shape, that is they are unidirectional. There is a need for many applications to develop a bi-directional ion drag pump. A new electrode structure that can be easily fabricated is also needed, since the three-dimensional emitter-collector structure for existing ion drag pumps requires a complicated fabrication process.

2. THEORY

An ion drag pump uses electric fields acting on space charges embedded in a fluid. An ion moves in the direction of the electric field and drags fluid. The charges can be injected directly into the fluid by sharp points or edges of the electrode, which is an emitter. The injected charges are dragged to the other electrode, which is a collector.

flow
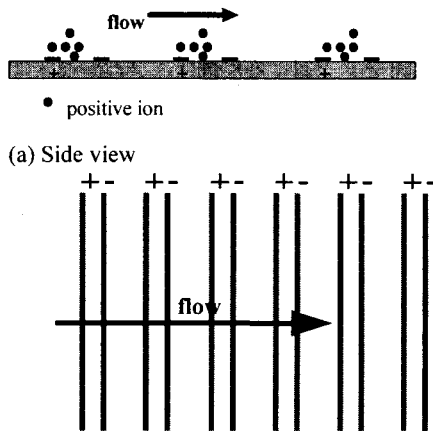
• positive ion

(a) Side view

flow

(b) Top view

Figure 1. Mechanism of ion drag pumping using unipolar conduction

The basic idea of a planar micro ion drag pump is the unipolar conduction in the fluid. That is, less mobile ions (positive ions in this work) contribute better to pumping [9].

Figure 1 shows the mechanism of ion drag pumping using unipolar conduction. When DC voltage is applied to the electrode arrays, the positive ions are injected from the edge of electrodes with positive sign, so the positive electrode acts as an emitter. Though the positive electrode has negative electrodes on both sides, the injected positive ions are dragged to the nearer one, which acts as a collector. Some of the momentum of the positive ions changes through friction into momentum of the fluid, so the fluid also moves from positive electrode to negative electrode. Charge exchange occurs on the edge of the negative electrode. Negative charges are injected and dragged by positive electrode the same way as the positive charges. But the fluid flow follows the movement of the positive charges in our experiment, which means that positive charge is less mobile than negative charge in the working fluid.

The motive force of an ion drag pump is the Coulomb force, so its pumping performance relies critically on the electrical properties of the fluid pumped, permittivity ε, conductivity σ, and viscosity μ. Generally high permittivity and low viscosity are required for high pumping performance. The flow rate u and pressure P are expected to show a quadric increase with DC voltage V and channel depth h as demonstrated in reference [9,10].

$$u \propto \frac{\varepsilon}{\mu} \cdot h^2 \cdot V^2 \qquad \text{(m/sec)} \qquad (1),$$

$$p \propto \varepsilon \cdot V^2 \qquad \text{(Pa)} \qquad (2).$$

3. FABRICATION

The electrode-pair array of the micro ion drag pump is shown in Figure 2. Since it has planar electrodes, fabrication of this model can be achieved more easily than the others previously made. Pumping occurs in the gap between two electrodes, and there are 30 cascaded pumping stages. The spacing between the cascaded pumping stages is 200 μm, and that between paired electrodes is 100 μm. The channel width is 3 mm and the width of each electrode is 100 μm. Total channel length is 30 mm.

$\downarrow$100 μm 100 μm $\downarrow$
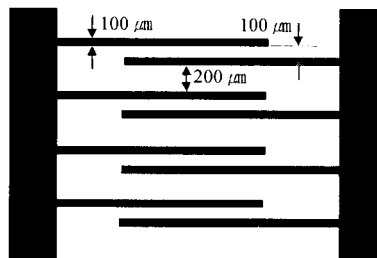
$\updownarrow$200 μm

Figure 2. Electrode pair array

Gold is necessary to avoid an electrolyte-electrode process. Gold electrode substrates are fabricated by additional Au electroplating. Cr or Ti is used as an adhesion layer for Au. After thermal evaporation of Cr/Au or Ti/Au on the glass substrate to 4000 Å thickness for adhesion layer (Cr or Ti) and to 3000 Å thickness for Au (Figure 3.(a)), electrodes are patterned by photolithography. Au is etched in the commercial gold etchant, then electrodes are patterned on the adhesion layer using 100:1 HF for Ti or Cr etchant for Cr (Figure 3. (b), (c), (d)). In order to cover the exposed Ti or Cr on the edge of electrodes, Au is electroplated additionally in the double boiler at 60 ℃

(Figure 3. (e)). The thickness of electroplated Au is more than 3 μm.
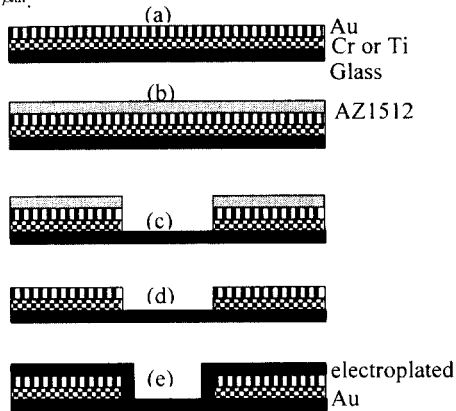

Figure 3. Fabrication process of electrode part

The channel part is fabricated by <100> silicon wet etching. Silicon nitride is used as an etch mask. Feeding holes are patterned by RIE with SF₆ plasma (Figure 4.(a), (b)), then a <100> silicon wafer is etched in a 40 wt % potassium hydroxide (KOH) solution (Figure 4.(c), (d)). After feeding hole etching, the channel is patterned through the same process as that for feeding holes. Then the designed channel depth is attained by timed wet etching of silicon.
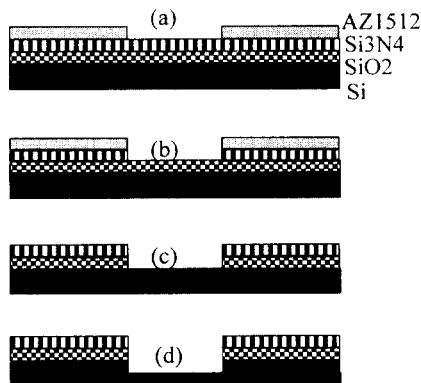

Figure 4. Fabrication process of channel part

The silicon channel is bonded to the glass substrate with planar electrodes, using epoxy-bonding, to complete the micropump (Figure 5, 6). After the bonding process, glass tubes of diameter 1mm are fixed at the inlet and outlet of the etched silicon channe

The apparatus for measurement is shown in Figure 7. Ethyl alcohol is used for measurement of pumping performance. Organic solvents such as alcohol or acetone have a high permittivity and a low viscosity, so they are expected to show a good pumping performance. The driving voltage varies from 20V DC to 130V DC.
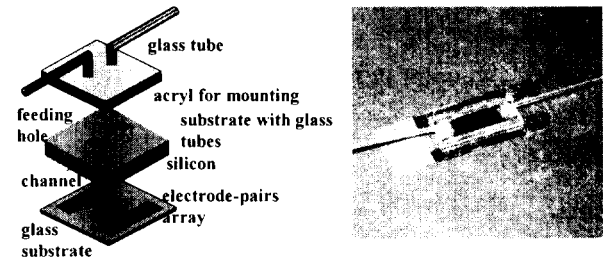

Figure 5. Packaging of planar micro ion drag pump (left)
Figure 6 . Planar micro ion drag pump (right)

The pump is driven bi-directionally for the measurement. When the polarity of applied DC voltage is changed the direction of flow also changes with some seconds of response time which depends on the material characteristics of fluid. The flow switching during operation is unstable and the switching time varies from some seconds to 1~2 minutes.

The movement of the fluid-air interface is observed for measurement of flow rate. The glass tubes attached vertically at the feeding holes are for generating pressure measurements. Inlet and outlet initially have the same fluid level. During operation, these levels change due to the pump pressure, and the difference between fluid levels of inlet and outlet is measured. Pump pressure can be calculated from that level difference and the mass density of the fluid pumped.

The pumps, with channel height 100 μm and 200 μm, are driven by DC voltage. For each pump, the flow rate and pressure is measured four times under the same conditions. Occasionally breakdown in the fluid occurs over 100V DC in the ethyl alcohol.

4. EXPERIMENT AND RESULTS
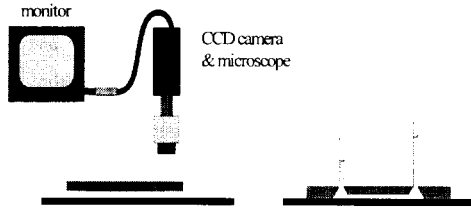
(a) Flow rate   (b) Pressure

Figure 7. Measurement system for flow rate and pressure

The flow rate vs. applied DC voltage is shown in Figure 8. Flow rate shows a quadric increase as a function of applied DC voltage under 60 V DC, but saturation and a decrease of pumping efficiency occurs over 60V DC. The interference between neighboring pumping stages becomes large with high DC voltage, and this makes pumping efficiency lower. According to Crowley's modeling the flow rate is to show an increase proportional to the square of channel depth. The flow rate in channel depth 200 μm is about four times larger than in channel depth 100 μm in Figure 8.

The pumping efficiency is expected to decrease with a longer channel length since the load to the pump increases. The channel length is fixed to 30 mm in our experiment.
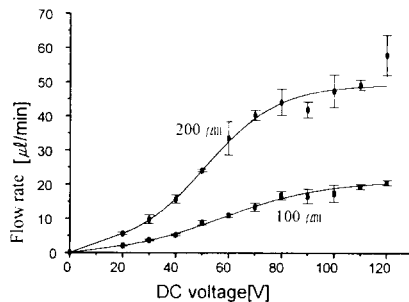

Figure 8. Flow rate vs. applied DC voltage

The measured pressure is plotted in Figure 9. The experimental values of pressure also show a quadratic increase with DC voltage. The solid line and dash line show that the pump is driven bi-directionally for measurement. Deviations in the experimental results are not large with the

same sample, but some experimental values (the flow rate and the pressure) differ greatly among samples. This is probably caused by profile differences of electrode edges made during the photolithography or by the packaging process. There is much room for improvement in the packaging process, such as anodic bonding of electrode substrate and silicon channel part in a batch process.
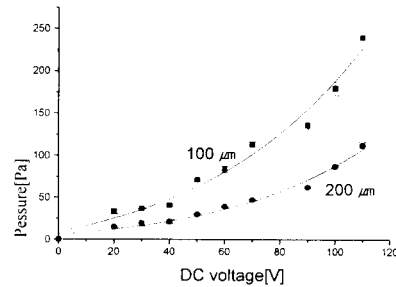

Figure 9. Pressure vs. applied DC voltage

The experimental values of flow rate is the same regardless of the flow direction in each pump. The additionally electroplated Au did not perfectly cover the exposed Cr or Ti on the edge of electrodes in some samples, so there is an electrochemical reaction of the fluid and the electrode in our experiments.

5. CONCLUSION

A micro ion drag pump with planar electrode pair array on the glass substrate is fabricated and experiments performed. The pump can be driven by DC voltage using unipolar conduction, and the flow follows electric field bi-directionally.

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