THE MICRO ION DRAG PUMP USING INDIUM-TIN-OXIDE (ITO) ELECTRODES

Lung-Jieh Yang, Jiun-Min Wang and Yu-Lin Huang

Department of Mechanical and Electro-Mechanical Engineering, Tamkang University,
#151, Ying-Chan Rd., Tamsui, 25137, Taiwan, ROC

Telephone: +886-2-26292474 Fax:+886-2-26209750 E-mail: Ljyang@mail.tku.edu.tw

ABSTRACT

This paper describes a micro ion drag pump, or an ejection type electro-hydrodynamic (EHD) micro pump, using Indium-Tin-Oxide (ITO) planar electrodes novelly. The ITO film for the electrodes makes anodic bonding easily and feasible in packaging the glass substrate (with ITO) hermetically with the silicon micro channels. Therefore, the scaling down or the miniaturization of ion drag pumps can be achieved herein. The ITO electrodes could drive the ethyl alcohol to have the maximum volumetric flow rate of 87 nl/min with applying a DC driving voltage of 40 Volts. More efforts and improvements on the pumping efficiency as well as the long-term stability of the ITO electrodes are acquired correspondingly.

INTRODUCTION

In ion drag or EHD pumping, fluid forces are generated by the interaction of electric fields and charges in the fluid. These pumps have interdigital electrodes, which are regularly spaced along a micro channel and require no moving parts like impellers, bellows or valves. The interactions of electric fields with induced electrical charges in the fluid yield a force that transfers momentum to the fluid [1].

The 1st micro ion drag pump using the silicon bulk micromachining and the wafer bonding technique was reported at MEMS'90 [2]. This pump has a lumped configuration and was not convenient in the on-chip integration of micro-fluidic systems. Ahn, et al. [3], therefore modified the 3-D geometry of silicon-grooved electrodes into the planar comb-shaped electrodes. They demonstrated additionally the bi-direction pumping capability with much simpler fabrication steps. The experimental flow rate of driving ethyl alcohol with DC voltage less than 100V is 10-40 μl/min.

Unfortunately, the packaging method in ref. [3] is still the epoxy bonding, which will encounter difficulties in the miniaturization and the mass production of the ion drag pumps. Moreover, the interference of gas bubbles due to the water electrolysis in the organic solution and the aging or even the oxidation issue of metal electrodes are still serious.

This paper depicted the usage of ITO electrodes in the fabrication of micro ion drag pumps to handle the technical issues mentioned above. We described the details in the followings.

DEVICE DESIGN AND FABRICATION

There are two main reasons in this paper favoring the electrodes of transparent ITO (, which is very popular in the LCD industry). First, the thin ITO electrodes sputtered on the glass substrate induces very small obstacle during the anodic bonding process with the silicon micro channel. The diffusion of ITO into the

0-7803-7744-3/03/$17.00 ©2003 IEEE.

silicon substrate or the break down (short-circuit) through the silicon-dioxide layer was not observed after the anodic bonding herein. Therefore, no complicated treatment of electrical isolation, e.g., the p-n junction implantation and the accurate pre-alignment before anodic bonding of the silicon micro channel and the electrical routing on the glass, is needed. This is essentially important during the practical scaling down of the ion drag pumps.

Second, ITO is composed of In_2O_3 (90-95%) and SnO_2 (10-5%), and is intrinsically oxidized. Hence, the degradation of ITO electrodes due to the unavoidable water electrolysis during the EHD pumping is supposed not apparent. The conventional protection way for using the Cr/Au as the reliable electrodes immersing directly in the liquid is to electroplate Au bumps as thick as possible to prevent the direct touch and oxidation of Cr layer with the liquid. It explains why the packaging method is the epoxy bonding in ref. [3], and why the ITO electrodes here benefit the process simplicity.

The processing sequence for the ITO EHD-driving electrodes is depicted in Fig. 1. We sputtered the 0.1-μm thick ITO film directly on the Pyrex-7740 glass and patterned it to the comb-shaped electrodes by the acid recipe of H_2O: HCl(37%): HNO_3(53%)=1: 1: 0.08 under the etching temperature of 55°C. The comb-shaped ITO electrode of 80μm wide and 80μm gap after etching is shown in Fig. 2.

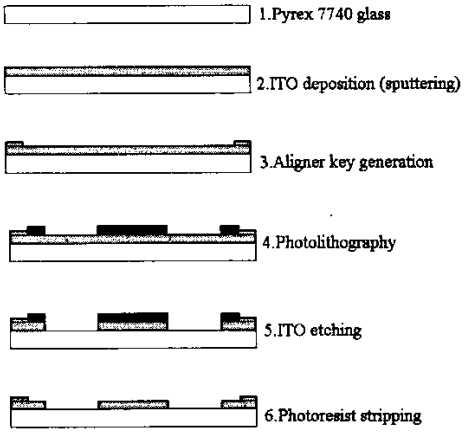

Figure 1 Cross section of fabrication process for ITO electrodes.

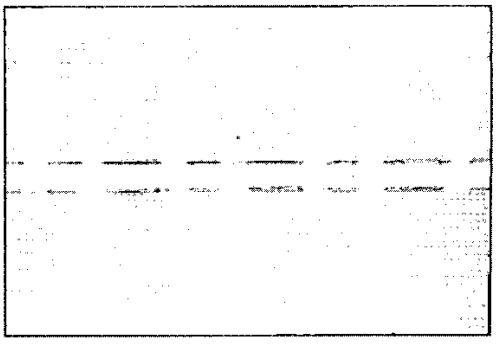

Figure 2 The interdigital comb-shaped ITO electrodes (of 80μm wide and 80μm gap) embedded in the microchannel.

The ITO electrodes in Fig. 2 are embedded between the Pyrex-7740 glass and another silicon wafer. There is a V-groove micro channel, which is anisotropically etched by KOH solution, available on the silicon wafer such that the electrodes are subject to the liquid driving. Figure 3 is the cross section view of the silicon microchannel which ITO interdigital electrodes were laterally placed across. The width and depth of the silicon V-groove channel are 100μm and 26μm, respectively, much smaller than the size dimension in ref. [3] with one order of magnitude.

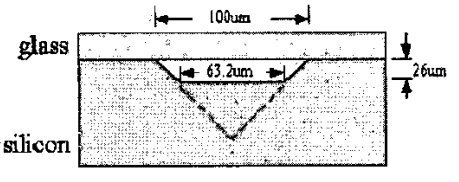

Figure 3 the cross section view and the size dimension of the silicon V-groove microchannel.

After being suffered by the anodic bonding process (400°C, 500-600V), the new completed micro ion drag pump is shown in Fig. 4.

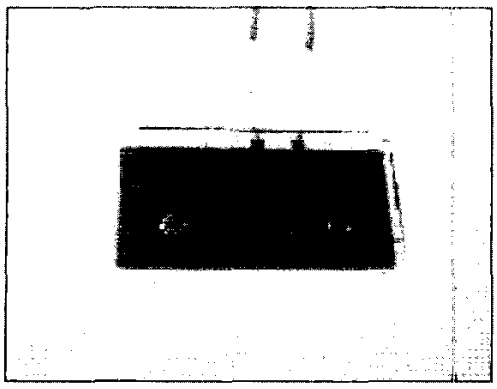

Figure 4 The completed micro ion drag pump composing of a channel-reservoir loop and 20 pairs of ITO electrodes. Two drilled holes are machined on the glass substrate in advance as the liquid-filling inlet/outlet.

Referring to the ref. [4], the theoretical maximum velocity of the laminar flow in the ion-drag pumping is shown in Eq. (1).

$$U \approx \frac{\varepsilon E^2 d^2}{12 \mu L} \qquad (1)$$

E is the electric field density, d is the depth of the micro channel, μ and ε is the viscosity and permittivity of the working liquid respectively, and L is the lateral gap between any two interdigital electrodes. According to Eq. (1), the theoretical maximum flow rate of this new design of ion-drag pump subject to 40 V DC is estimated to be 270 nl/min.

TEST RESULTS AND DISCUSSION

Here, we proved experimentally that the new ion drag micro pumps using ITO electrodes function well and are more stable than the pumps using evaporated Cr/Au electrodes. We recorded the EHD pumping velocity of the moving front of some specific gas bubbles (generated from ITO electrodes) as well as the 3μm-diameter bits in the ethyl alcohol channel-flow by an optical microscope. Figure 5 are the continuous, moving images of the EHD pumping flow. The water electrolysis in Fig. 5 still appears when the driving voltage is larger than 10V, but the liquid columns separated by the gas bubbles move steadily according to the polarity of the electric field in the micro channel flow. The moving direction can be changed if we alter the electrical polarity. In other words, this micro ion drag pump has the capability of

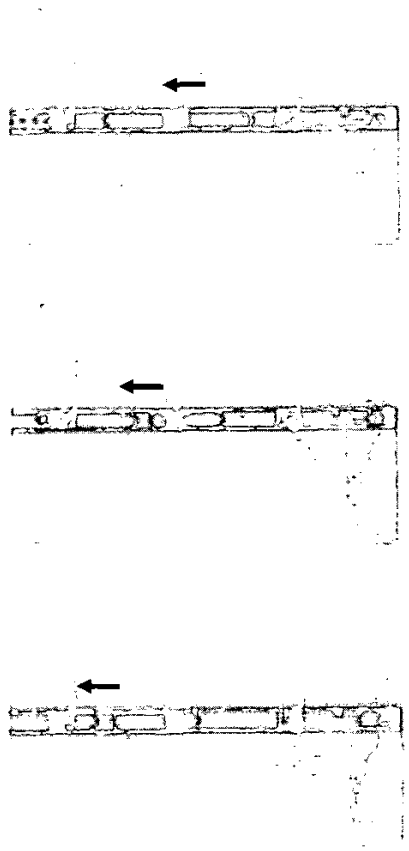

Figure 5 The three continuous captured images of the EHD pumping flow (ethyl alcohol).

bi-directional driving for non-conductive liquid. Most essentially of all, no delamination or pealing of ITO electrode is found.

The experimental result of pumping rate versus DC voltage is shown in Fig. 6. The maximum volumetric flow rate of the ethyl alcohol is 87 nl/min subject to the DC voltage of 40 V. Such a result is only 32% of the theoretical value mentioned in the previous section. Figure 6 also shows the tremendous decrease of pumping efficiency with high DC voltages. Actually, the ITO cathode-electrodes begin to degrade or even open-circuit if the continuous DC voltage driving of 15 V is beyond 10 minutes. This point means the modification of ITO durability for EHD driving is still necessary.

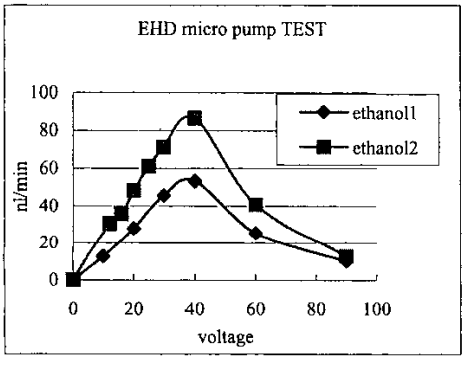

Figure 6 The pumping volumetric (ethyl alcohol) flow

CONCLUSION

This paper described a micro ion drag pump using ITO electrodes novelly. The micro pump could drive the ethyl alcohol to have the maximum volumetric flow rate of 87 nl/min with applying a DC driving voltage of 40 Volts. Although there is still plenty of room for improvement on the pumping efficiency and the long-term stability of the micro ion drag pump, this work reduces the EHD pumping flow rate down to nl/sec successfully. We believe that such a design of electrode material could be applied to some topics, e.g., the liquid-enhancement pumping of heat-pipe [5], pumping for active evaporative cooling [6], or the mixing of fluids of different conductivities in the biological environments [7] promisingly.

ACKNOWLEDGEMENT

The authors appreciate the financial support of this work from the National Science Council, Taiwan (ROC), with the project number of NSC-90-2218-E-032-015. The authors also want to thank the helps from Dr. Yu-Chong Tai and Dr. T.-J. Yao of the Micromachining group, Caltech, USA.

REFERENCES

[1] M. Madou, Fundamentals of Microfabrication, 1st ed., p.433, CRC Press, 1997

[2] A. Richter and H. Sandmaier, "An EHD pump", Proc. of IEEE MEMS'90, 1990, pp.99-104

[3] S. Ahn and Y. Kim, ""Fabrication and experiment of a planar micro ion drag pump", Sensors and Actuators A, 70 (1-2), pp.1-5, 1998

[4] J.M. Crowley, et al., "Selecting a working fluid to increase the efficiency and flow rate of an EHD pump", IEEE Transactions on Industry Applications, 26(1), pp.42-49, 1990

[5] J.E. Bryan and J. Seyed-Yagoobi, "Heat transport enhancement of monogroove heat pipe with electrohydrodynamic pumping", Journal of Thermophysics and Heat Transfer, 11(3), pp. 454-460, 1997

[6] J. Darabi, et al., "An EHD polarization micropump for electronic cooling", Journal of Microelectromechanical Systems, 10(1), pp.98-106, 2001

[7] J.-W. Choi, "An active micro mixer using EHD convection", Solid-State Sensor and Actuator Workshop, Hilton Head, 2000, pp.52-55.