# ELECTROLYSIS-BASED DIAPHRAGM ACTUATORS

Changlin Pang[1], Yu-Chong Tai[1], Joel W. Burdick[2], and Richard A. Andersen[3]
[1]Caltech Micromachining Lab, California Institute of Technology, Pasadena, CA 91125, USA
Tel: (626) 395-2254; Fax: (626) 584-9104; E-mail: changlin@caltech.edu
[2]Department of Mechanical Engineering, California Institute of Technology, Pasadena, CA 91125, USA
[3]Division of Biology, California Institute of Technology, Pasadena, CA 91125, USA

Recent studies using neuroprobes indicate that it is highly desirable for the probes to have moving (both forward and backward) capability so that it can track a specific neuron in the brain, because live neurons do move around. However, for brain use, the movable neuroprobes need to be powerful (to penetrate brain tissue), high density, low power, bidirectional and latchable (without power). We have since proposed to develop electrolysis-based actuators for the movable probes. This work presents our initial work on a large-force bidirectional electrolysis actuator fabricated with MEMS technology. Up to 100μm (comparable to the averaged neuron-to-neuron distance) of movement was achieved by a 3-mm diaphragm. The bidirectional movement can be linearly controlled by small currents. The actuator is proved latchable. Overall the results support the promising aspects of electrolysis-based movable neuroprobes.

The actuator schematic is in Figure 1, where two neighboring chambers are etched in the silicon chip using DRIE. The central chamber is for hydrogen (generated by electrolysis), and the outside for oxygen. The chamber volume ratio is 2:1 assuming stoichiometric electrolysis. These two chambers are separated by a high-aspect-ratio ring-shaped wall. On the outside, two channels are used to fill electrolyte into the chambers. Electrolysis electrodes are made on a separate glass chip, which is later bonded to the silicon top using polymers. The central silicon membrane (with a thickness of 40μm) deflects under the pressure generated by electrolysis. Separating oxygen and hydrogen in different chambers prevents the recombination of them; therefore, the diaphragm can maintain its position even the electrolysis is off, hence latchable. To achieve bidirectional movement, we can reverse the electrolysis polarity. If the electrolysis is reversed, the newly generated gases will mix and the oxygen and hydrogen recombine (in the presence of platinum catalyst), but only to the controlled amount defined by the reversed electrolysis.

The process for the silicon top chip (Figure 2a) has a two-level DRIE etching. The deep etching is for the gas chambers. The shallow etching is to make conduction and electrolyte injection channels. A variety of actuator sizes have been made ranging from 400 to 3000μm (Figure 3). A Ti/Au layer is for the electrode on the glass chip (Figure 2b). Figure 4 shows the electrolysis performed by the electrode chips. Bonding polymer (either parylene or photoresist) is applied to bond the silicon top and the glass bottom chips (Figure 2c). The cross section of a completed device is showed in Figure 5. Filling the chambers with electrolyte is done by immersing them into the fluid under vacuum. This process works well as demonstrated by the fluorescence photogragh (Figure 6). A small amount of epoxy is then used to seal the electrolyte filling hole. Electrolysis tests are then performed on the actuators (Figure 7a). Figure 7b shows the deflections of diaphragm with different diameter under 5V voltage. The curves of electrolysis voltage vs. current for the devices with different sizes are shown in Figure 8a. Note that actuator movement can be linearly controlled by a current (Figure 8b). The latchable and reversible movement is also demonstrated in Figure 8c-d. It is important to see that the diaphragm can hold the position without power (Figure 8c). Figure 8d then shows several cycles of bidirectional movements, proving our concept feasible.

**References:**

[1] Colin G. Cameron and Michael S. Freund, "Electrolytic actuators: Alternative, high-performance, material-based devices", PNAS, 2002. 99(12): pp.7827–7831.
[2] Jun Xie, Yunan Miao, Jason Shih, Qing He, Jun Liu, Yu-Chong Tai, and Terry D. Lee, "An Electrochemical Pumping System for On-Chip Gradient Generation", Analytical Chemistry, 2004. 76 (13): pp. 3756-3763.
[3] C-T Pan, H Yang, S-C Shen, M-C Chou and H-P Chou, "A low-temperature wafer bonding technique using patternable materials", J. Micromech. Microeng. 2002. 12: pp. 611-615.

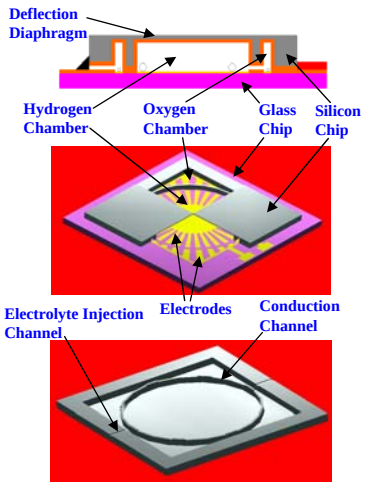



Figure 1. Schematic view of the electrolysis-based actuator.

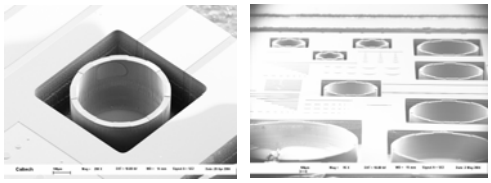
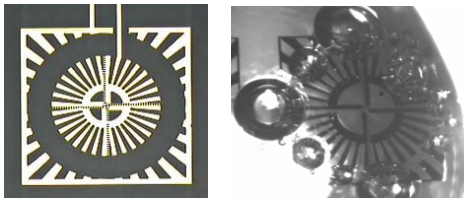


Figure 3. SEM pictures of the actuator chambers.



(a) (b)

Figure 4. (a) Electrodes of the actuator. (b) Electrolysis generated by the electrodes.

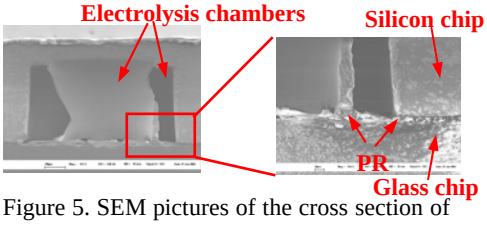
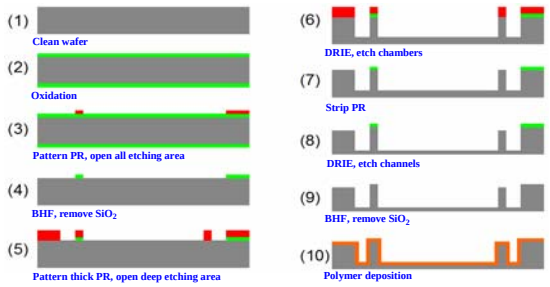
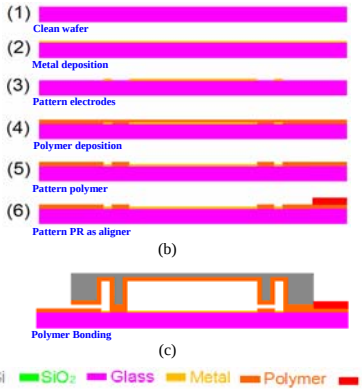



Figure 5. SEM pictures of the cross section of the device.

Figure 6. Fluorescent microscope image of the liquid-filled chamber




(a)



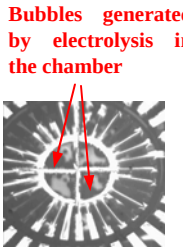

(b)



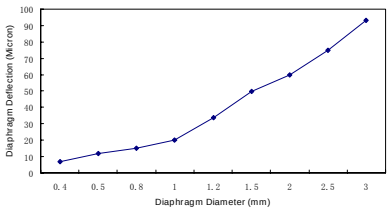

(c)




Figure 2. Fabrication Flow.

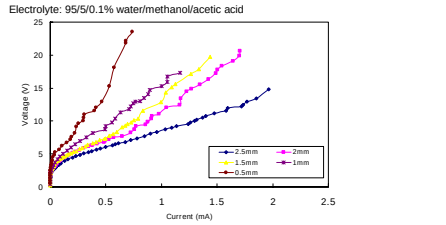



(a)

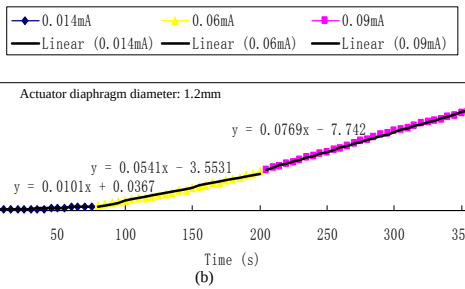



(b)

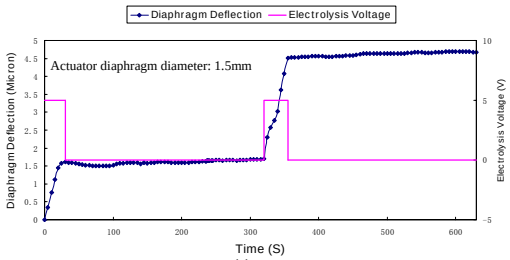
Figure 7. (a) Electrolysis in the actuator's chamber. (b) The deflection of different size actuators under 5V voltage.



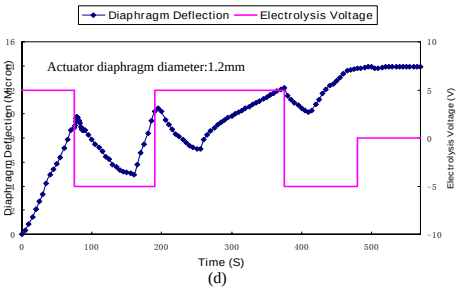

(a)




(b)




(c)




(d)

Figure 8.(a) Electrolysis voltage vs. current curve for the devices with different geometries. (b) Diaphragm deflection under different driving current. (c) Actuator's latching capability. (d) Actuator's reversing capability.