

Electrolysis-based Parylene Balloon Actuators for Movable Neural Probes

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Abstract—In order to track a specific neuron and keep good sampling neural signals during chronic implantation, the neural probes are highly desired to have moving capability. This paper presents a novel electrolysis-based parylene balloon actuator fabricated with MEMS technology. The actuator is integrated with silicon probe to make it movable. A new fabrication technology has been developed to build a parylene balloon structure with silicon spring structure, electrolysis electrodes and electrolyte inside. By applying little current to electrolysis electrodes, high pressure is generated inside the parylene balloon by electrolysis. The spring structure is stretched with the parylene balloon expansion. Therefore the neural probe is moved by the actuation. The electrolysis actuator can generate large stain and pressure, requires modest electrical power and produces minimal heat. Due to the large volume expansion obtained via electrolysis, the small actuator can create a large force. The new electrolysis actuators for movable neural probes have been fabricated and validated.

Keywords—Electrolysis actuators; movable neural probes; parylene balloon actuators

I. INTRODUCTION

Recent studies using neural probes indicate that it is highly desirable for the probes to have moving capability. Major advantages of the autonomously movable electrode concept are: 1) the initial positioning of electrodes to optimize the number of active cells; 2) the possibility to select cells with particular response properties; 3) the ability to track cells to prevent their signal from being lost; and 4) the potential to break through glial scars to seek fresh tissue in order to prolong the useful lifetime of the recording channel at the electrode tip [1].

For brain use, the movable neural probes need to be powerful (to penetrate brain tissue), high density, low power,

bidirectional and latchable (without power). Unfortunately, many MEMS actuator technologies are not suitable for chronically implantable movable probes. Table I summarizes some of the relevant properties of MEMS actuators that have been developed to date, as well as the electrolysis actuator we are developing. Electrostatic actuators [2, 3] and piezoelectric [4, 5] actuators often require high voltage (>100V). Not only are high voltages apt to interfere with neural recording, voltage leaks in the case of component failure may damage neural tissue. Some actuator types also suffer from low arrayability (the ability of the actuators to be formed into arrays), due to form factor limitations and other engineering issues. Thermo-pneumatic actuators [6, 7] cause excessively high temperature rise, which can cause tissue damage and loss of brain function in the probe's vicinity. Similarly, the most miniaturized electromagnetic motors, such as MicroMo's (1.9mm O.D.) motors, require hundreds of mW of power, a delicate gearbox for operation, and are too large for formation into arrays. Generally, most MEMS actuation techniques, such as shape memory alloy actuators [8-10] are not "lockable". That is, they require continual application of energy to maintain their position, which can cause unacceptable tissue heating. In summary, most commonly investigated MEMS actuation techniques suffer from one or more drawbacks for our needs.

This paper presents our initial work of a new class of electrolysis-based MEMS actuators that overcome many of the problems inherent in known techniques.

II. ELECTROLYSIS TECHNIQUE

Electrolysis is a technique for converting electrical energy to pneumatic energy. The two electrochemical half-reactions for the electrolysis of water are shown in Eqs. 1 and 2. The net

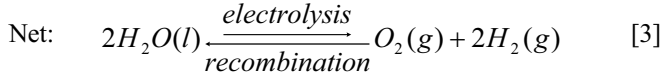
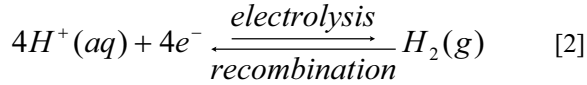
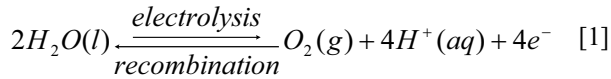
TABLE I. SOME OF THE RELEVANT PROPERTIES OF MEMS ACTUATORS

Actuation Type	Power Supply	Heat Dissipation	Output	Lockable	Arrayable
Electrolysis actuator	Low current & voltage	Low	Large force & displacement	Yes	High
Shape-memory alloy	High current & power	High	Large force & displacement	No	Low
Piezoelectrics	High voltage	Medium	Large force, small displacement	No	Low
Electromagnetics	High current	High	Medium force	No	Poor
Electrostatics	High voltage	Low	Small force & displacement	No	High
Thermoelastic	High current & power	High	Large force, small displacement	No	Medium
Electroosmotics	High voltage	Medium	Large force, small displacement	No	Low

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reaction (Eq. 3) entails a 3:2 stoichiometric ratio of gas to liquid and occurs via the transfer of four equivalents of electrons through an external circuit.



Electrolysis is a good method for high-performance actuation. Electrolysis can theoretically achieve a strain of 136,000%, and is capable of generating a pressure beyond 200 MPa [11]. The Electrolysis-based parylene balloon actuators described in this paper require modest electrical power and produce minimal heat. Due to the large volume expansion obtained via electrolysis, the small actuators can create a large force. While electrolysis-based actuators may not extend rapidly, our preliminary results show that such speed is unnecessary. Overall the results support the promising aspects of electrolysis-based movable neural probes.

III. DEVICE DESIGN

The device design is shown in Figure 1. The movable neural probe is combined with two main parts: silicon probe and movement actuator. Metal sensing electrodes, which are used to detect neural signals, are at the tip of a 2mm long silicon probe. A silicon spring structure is on the base of the silicon probe shank, providing strong enough base during inserting the probe into brain tissue, at the same time, performing as the flexible part during probe moving. Different silicon spring structures are designed (Table II). Electrolysis electrodes are on the silicon spring structure. The silicon spring is surrounded by a balloon structure made by parylene: a biocompatible polymer. Electrolyte is filled and sealed inside the parylene balloon. By inputting current to electrolysis electrodes, electrolysis will generate gases and build pressure inside the parylene balloon. Parylene balloon will then expand under the pressure, stretch the spring and push the probe shank moving forward. A parylene flexible cable is integrated for electronic connection.

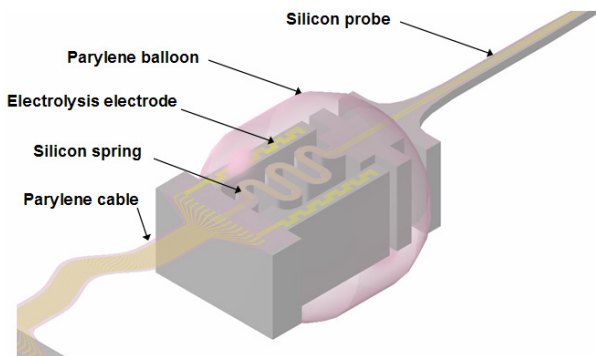


Figure 1. Electrolysis-based parylene balloon actuator design.

TABLE II. SPRING STRUCTURE PARAMETERS OF THE ACTUATORS.

Single spring structure			Double spring structure		
Design parameters: a=b=50μm			Design parameters: a=b=50μm		
	L (μm)	Turns		L (μm)	Leaves
Type 1	300	5	Type 1	650	3
Type 2	500	5	Type 2	1000	3
Type 3	1000	5	Type 3	650	4
Type 4	300	7	Type 4	1000	4
Type 5	500	7	Type 5	650	5
Type 6	1000	7	Type 6	1000	5
Type 7	300	9	Type 7	650	6
Type 8	500	9	Type 8	1000	6
Type 9	1000	9	Type 8	1000	6

IV. FABRICATION RESULTS

Silicon probe is fabricated using double side DRIE process, which is developed in our lab [12-14]. Silicon spring structure is fabricated on the probe shank base as well. Different geometric spring structures have been fabricated, as shown in Figure 2. A special sacrificial parylene coating process has been developed to coat a 10 μm parylene layer surrounding the spring structure to form the parylene balloon structure. A hole in size of 5μm to 10μm for releasing sacrificial photoresist and filling electrolyte, is poked on the parylene balloon at the base of the spring structure using a hot metal probe. A fabricated device is shown in Figure 3.

Filling the parylene balloon with electrolyte is done by immersing it into the fluid under vacuum, where the air in the chambers is first evacuated and then immediately filled by the liquid. This process works well as demonstrated by the fluorescence photograph shown in Figure 4. A small amount of biocompatible epoxy is then used to seal the electrolyte filling hole.

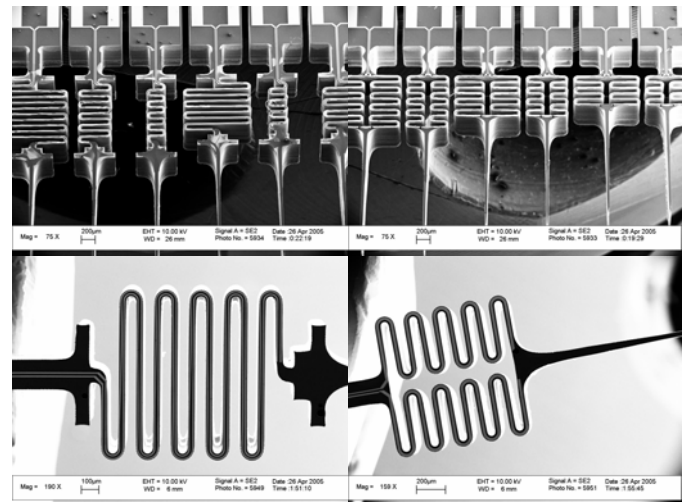


Figure 2. SEM pictures of the silicon spring structures with different geometric parameters.

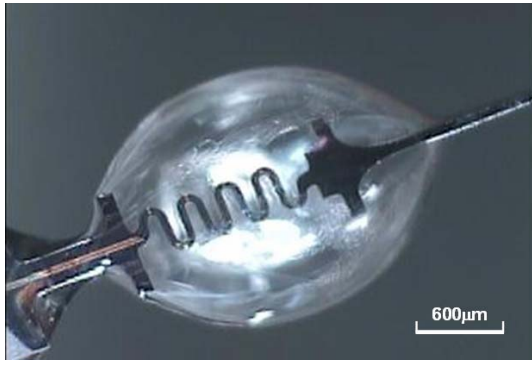


Figure 3. Fabricated parylene balloon actuator.

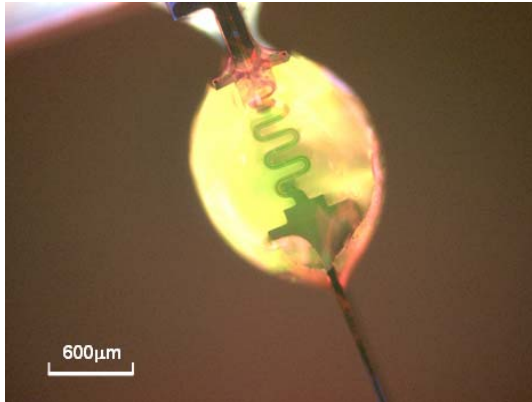


Figure 4. Fluorescence picture showing the parylene balloon is fully filled with electrolyte.

V. TESTING RESULTS AND DISCUSSIONS

Probe movement tests are first performed on the actuators by electrolysis. As shown in Figure 5, gas bubbles are generated inside the parylene balloon after inputting current to the electrolysis electrodes. Therefore the probe shank is pushed to move. The movement is calibrated by an electromagnetic displacement sensor with 0.02 μm resolution.

Figure 6 shows one successful demonstration of the actuator movement by applying little current. Figure 6(a) shows the current input; Figure 6(b) shows the displacement curve of the probe shank. Because the actuator only has one electrolysis chamber, Oxygen and hydrogen are mixed and recombine quickly. As a result, for the current design, the electrolysis efficiency is relatively low and the actuator is not latchable (the displacement drops back because of oxygen and hydrogen's recombination, after the current is off). In order to improve the efficiency and have latchable and reversible function, separated electrolysis chambers (one for oxygen, one for hydrogen) are needed [15].

VI. CONCLUSIONS

A new electrolysis-based parylene balloon MEMS actuator is first designed and demonstrated. The preliminary testing result shows promising aspects of the electrolysis-based actuators for movable neural probes



Figure 5. Electrolysis inside the parylene balloon of the actuator.

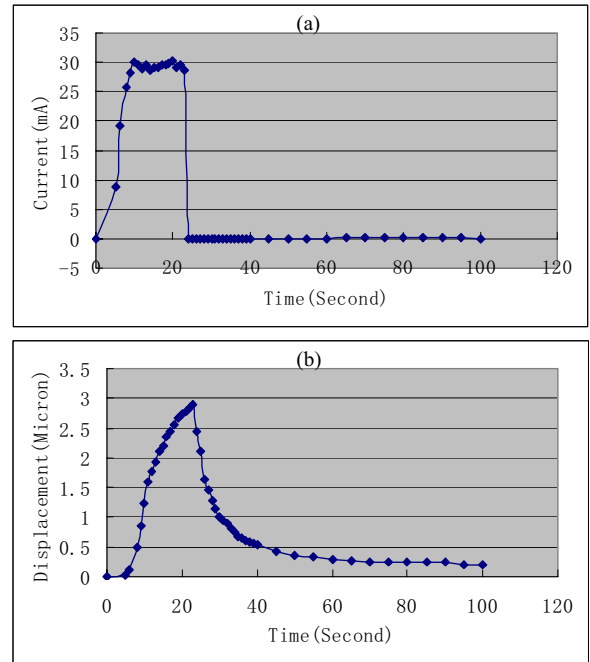


Figure 6. One demonstration of the actuator movement: (a) current applied to the electrolysis actuator; (b) probe movement.

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