BIOMIMETIC MICRO ACTUATORS BASED ON POLYMER ELECTROLYTE / GOLD COMPOSITE DRIVEN BY LOW VOLTAGE

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ABSTRACT

This paper reports a method to make a biomimetic micro actuator having large displacement and uniquely controllable motion. It is based on a polymer electrolyte membrane / gold composite in which the identity of the cation influences its motional response to stimulus. The gold electrode is fractal-like with exceptionally high interfacial area. Its motional response and versatility are illustrated by several examples. Using various connection schemes, complex and life-like modes of behavior can be simulated.

INTRODUCTION

Micro-electro-mechanical devices can be made with current IC technology. However, the technology is complex and expensive. There is considerable present interest in developing mechano-chemical materials based on the swelling of ion exchange membranes to act as micro-actuators. These so-called mechano-chemical actuators convert chemical, thermal or photon energies into mechanical energy due to polarity change. These devices are simple and easy to design and fabricate. The most promising mechano-chemical systems are those driven by electric stimuli. Unfortunately, the speed and extent of bending motion in these actuators are still rather limited. A previous study reported that the perfluorosulfonic acid film (Nafion117) plated with platinum makes fast bending motion without electrolytic gas evolution [1-4]. Perfluorinated polymer electrolyte membranes in the carboxylic acid form are superior to the corresponding sulfonic acid form for this application. They have higher ion-exchange capacity and better mechanical strength. Gold is a promising material as electrode, being stable in acid, yet softer, more conductive, and less active in electrochemical reactions than platinum [5]. High interfacial area between the electrodes and polymer electrolyte should lead to larger deformation [6]. This paper reports a significant advance in performance by plating with ultra-fine gold, giving displacements ten times higher and biomimetic motion.

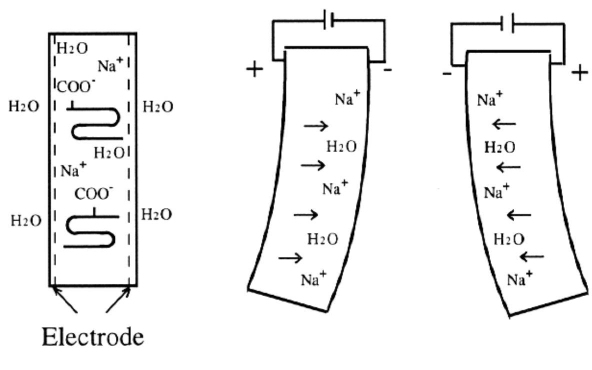


Fig. 1 Schematic of the bending motion

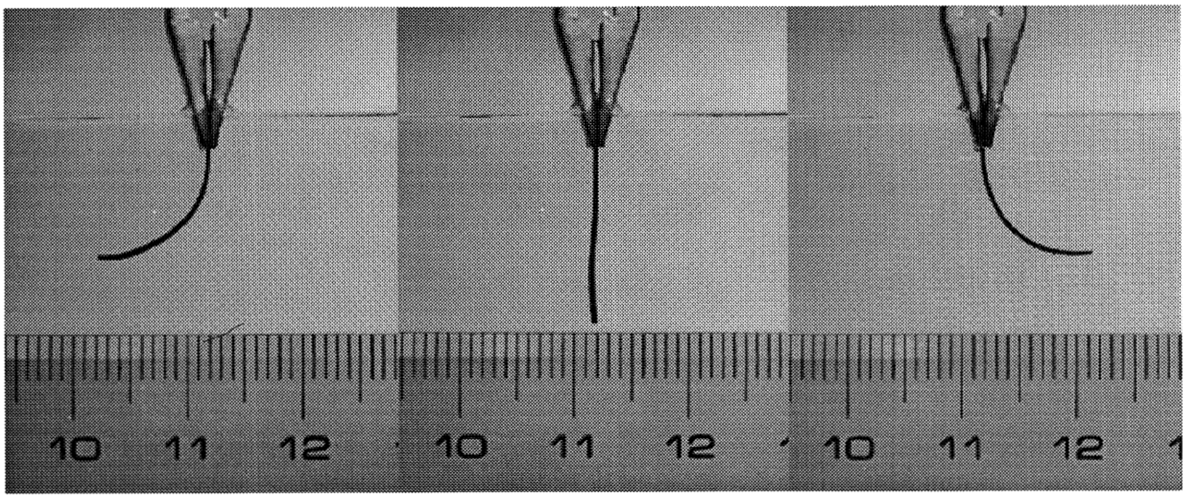


Fig. 2 Bending motion of the composite membrane (±2.0V) in water

WORKING PRINCIPLE

The mechanism of the bending motion (Fig.1,2) is due to uni-directional electroosmosis by cations, with their water solvent sheath, toward the cathode. Water enrichment at the cathode and depletion at the anode causes bending due to differential swelling and shrinkage.

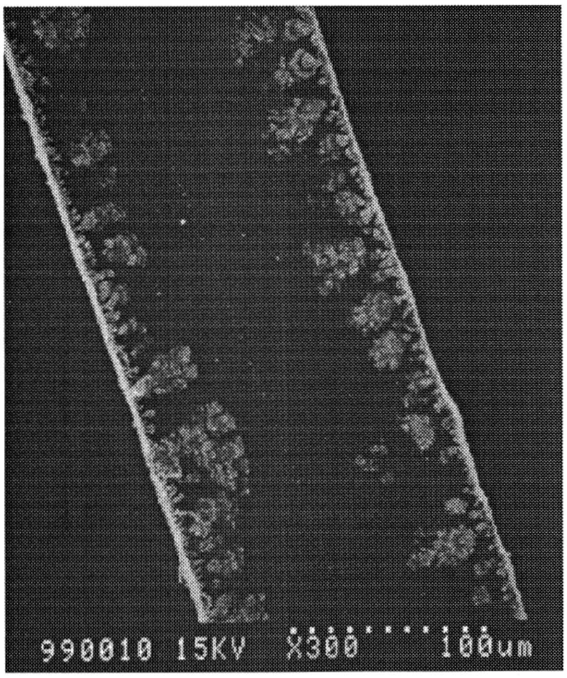


Fig.3 SEM micrograph (X250) of the five times plated membrane

PREPARATION AND ELECTRODE DEVELOPMENT

After surface roughening by "dry-blasting", both sides of a perfluoro carboxylic acid ion exchange polymer membrane, Flemion®(Asahi Glass Co. Ltd., 1.44meq/g-resin, 0.14mm thick) were chemically plated with gold as follows. The perfluorocarboxylic acid membrane was soaked in Au(III) di-chloro phenanthroline complex solution for >10 hours, rinsed, and then any adsorbed Au(III) cation complex in the membrane was reduced in aqueous sodium sulfite. By sequential adsorption / reduction cycling, a suitable pair of gold electrodes with a fractal-like structure may be grown (Fig.3).

This high interfacial area between the electrodes and

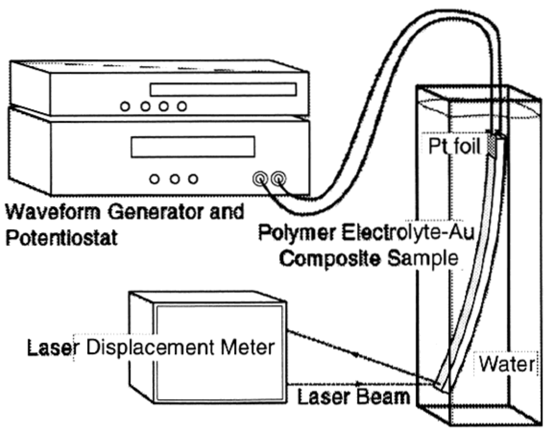


Fig. 4 A schematic of displacement measuring system

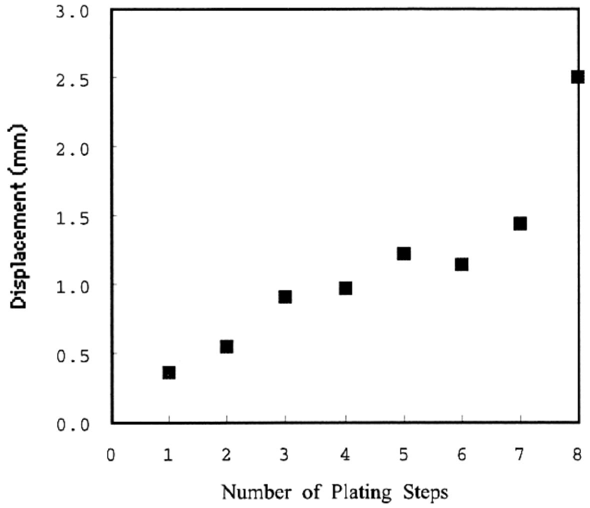


Fig. 5 Peak to peak displacement of the composite (±2.0V square-wave) vs. number of plating steps (Sample size: 1.0mm X 5.0mm)

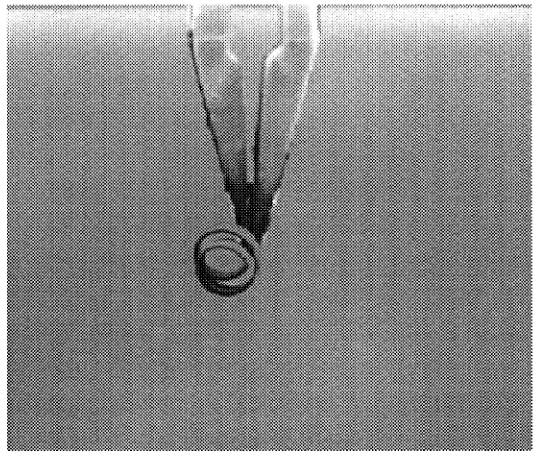


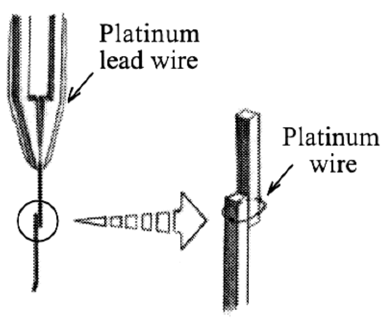
Fig. 6 Continuous spiral formation with $R_nNH_{4-n}^+$-loaded ribbon

polymer electrolyte leads to larger deformation (Fig.4, 5). The measured deformation (Fig.4) progressively improves with cycling (Fig.5).

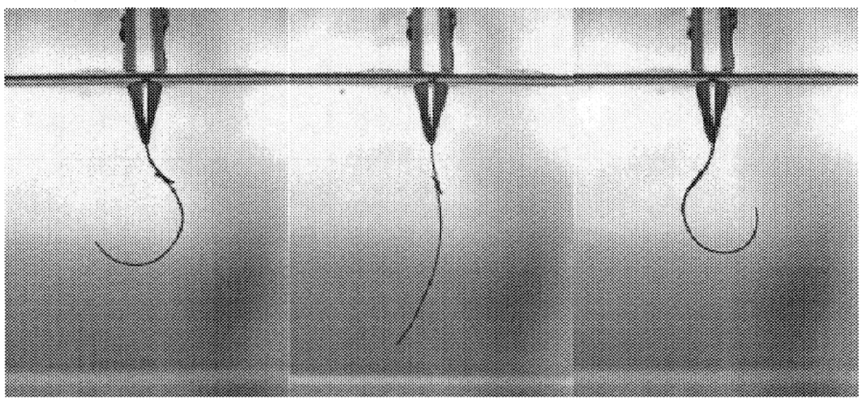
BIOMIMETIC MOTION

By soaking the membrane in aqueous LiCl or $R_nNH_{4-n}Cl$ (R: Alkyl group), different types of response are observed. With Li^+ ion incorporated, the response is fast. In contrast, with bulky alkylammonium groups, deformation is slower but extensive, forming a continuous spiral from a 20mm length ribbon (Fig.6).

The first example consists of a double-segment ribbon (Fig.7), connected in reverse polarity with fine platinum wire. If the upper portion is pre-soaked in Li^+ ion solution and the lower in $R_nNH_{4-n}^+$ ion solution, the motional response resembles that of a worm. Upon stimulus (±2.0V, 0.5Hz square wave), the two segments bend in opposite directions and at different speeds, creating an overall life-like effect.



a. Connection scheme



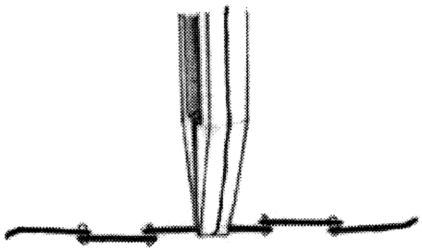
b. Motion image

Fig. 7 Worm Model

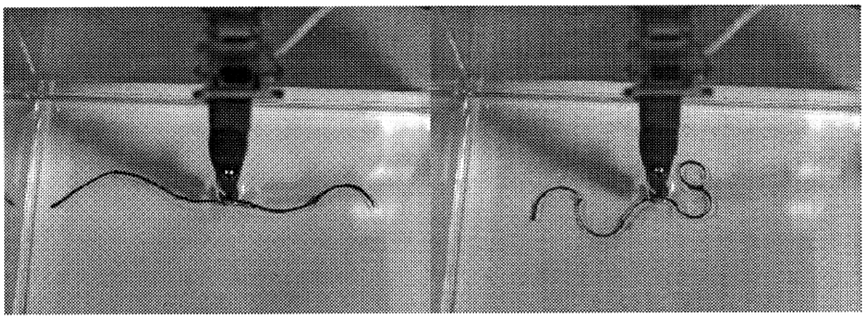
A more elaborate arrangement with five segments (Fig.8) pre-soaked in RnNH4-n+ ion, extends and contracts slowly over 5 to 10cm when stimulated at lower frequency (±3.0V, 0.1Hz square wave). This resembles more a snake.

The jellyfish model (Fig.9) is a single piece with eight-arms free to move in the same direction. Pre-soaked in RnNH4-n+ ion solution and stimulated ±3.0V, 0.5Hz (square wave), a centrosymmetric motion is caused which resembles a "grab-and-release" effect. With greater sophistication, an independently-controlled arm movement could be set-up and stimulated variously to create complex life-like effects such as "swimming" and "walking".

The example actuators shown here are sensitive to the

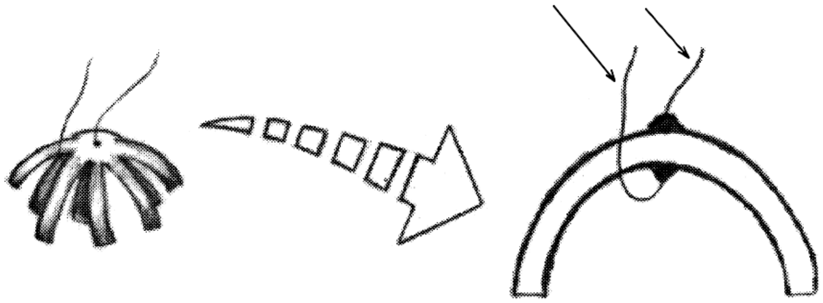


a. Connection scheme

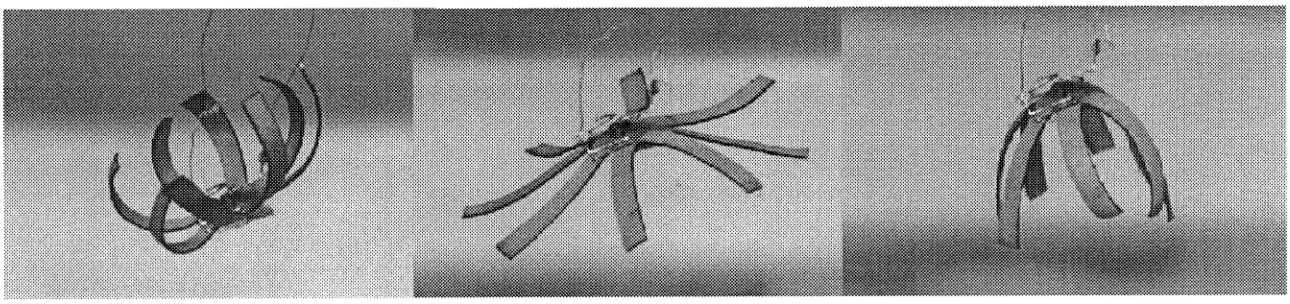


b. Motion image

Fig. 8 Snake Model



a. Connection scheme



b. Motion image

Fig. 9 Jellyfish Model

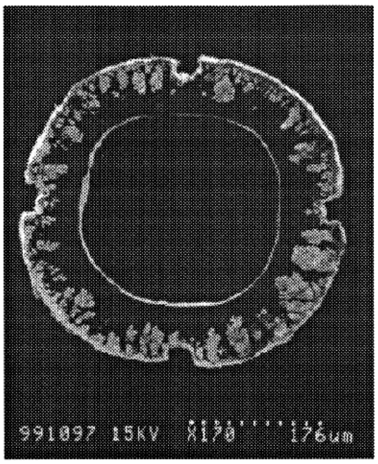


Fig.10 SEM micrograph (X170) of the eight times plated tube with four electrodes

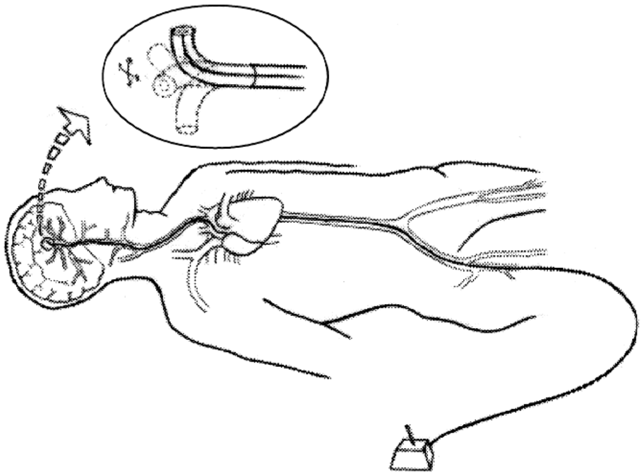


Fig.11 Schematic of active catheter withtubular actuator tip

type of electrical stimulation, and have great flexibility in motional response depending on the incorporated cation. The principle is currently being extended to a tubular form with quadrupolar directional control for medical applications. Using a simple joystick, this arrangement may serve as a superior active catheter for in-vivo surgery, e.g., in treating brain aneurysm (Fig.10,11).

CONCLUSIONS

1) A gold-plated polymer electrolyte composite has been developed to serve as a micro-actuator with good displacement response under electrical stimulation.
2) It is amenable to easy miniaturization due to its structural simplicity and mechanical flexibility.
3) Complex biomimetic motion can be simulated and controlled by the actuator's sensitivity to chemical environment (cations) and the quality of electrical stimulation (voltage, frequency, wave form).

ACKNOWLEDGMENT

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