A Laser-micromachined Underwater Micro-cell-gripper Using Ionic Conducting Polymer Film

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Abstract

The manipulation of biological elements is a key technology for many new demanding applications in bio-MEMS. In this paper, we describe a development of a biological cell gripper using a new breed of electroactivated polymer material. The ability to produce a large deflection with a small input voltage (~5V) means that this type of material has high potential not only for biological applications, but also for underwater MEMS and artificial muscles for space robots. A special laser-micromachining process is introduced to cut out arrays of griping devices which can potentially be integrated with IC components. Individual actuators with dimensions of 200μm x 200μm x 3000μm were realized. We will report on the design, fabrication procedures and operating performance of the polymer actuators. The successful development of these actuators will enable effective and fast control of underwater micro objects and lead to new applications in cellular manipulation.

Introduction

The ability to identify and isolate cells is very important and is fundamental to numerous biotechnology and medical applications. A micro-device to grasp and selectively manipulate micro-objects in a fluid is highly desired. A common cell manipulation technique found in microbiology labs is cell transfer via pipette suction. However, it is not accurate enough to isolate and move single cells. Electromanipulation [1] is also another alternative but the high electric field gradients present at the electrode surfaces may possibly damage the particles.

Ionic conducting polymer films (ICPF) is a newly invented material. It is a sandwich of a film of perfluorosulfonic acid polymer that is between two thin film layers of metal such as gold, which serve as metallic electrodes. For actuation, we utilitze the perfuluorosulfonic acid polymer film's ability to absorb water. This increases the mobility of and number of cations in the film. Micro-actuation devices can be made based on the swelling of the ion exchange polymer membranes. Strips of ICPF can give large and fast bending displacement in the presence of a low applied voltage in wet condition. However, specially coated ICPF actuators can also be made to operate in dry conditions. Thus, ICPF have a high potential to be incorporated into sensors or actuators where a large displacement is desired. Recently, NASA and Artificial Muscles Research Institute have been developing telerobotic devices and space mechanisms using this kind of efficient miniature actuators [2]. In addition, Osaka National Research Institute in Japan has been developing micro-catheter system, micro pumps, and a micro-robots using ICPF [3]. In this paper, we propose a new micro gripping device, which is miniaturized to manipulate a single cell.

Underwater micro-cell-gripper

Actuation of ICPF strips occurs when a voltage difference is applied across the strips. For our experiments, we chose an ICPF produced by DuPont under the trade name Nafion 117. Ion migration will cause the strip to bend towards the anode side. It is also possible to control the frequency of actuation and the magnitude of deflection of the strips. Using laser-machining techniques, we have designed and fabricated the star-pattern micro-cell-gripper as shown in Figure 1 below.

The individual actuator legs have a width of 200μm and the diameter of the star-patterned actuator is 3mm. The thickness of the actuator is constrained by the thickness of the Nafion thin film, which is about 180μm. For actuation, we applied a low voltage (2-10V) across the

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electrodes. Two pairs of opposite legs will bend towards their anode side and implement the gripping motion. By varying the frequency and magnitude of the input voltage signal, which actually changes the electric field across the metal electrodes, we can control the bending frequency and deflection angle of the gripper. Introducing bonding techniques and IC technology, it is possible to integrate arrays of micro-grippers on a micro chip and bond the anode side to the chip. In order to grip micron sized biological elements, we are currently further reducing the actuator size and these results will be reported later. Using a microscope-based monitoring procedure, we anticipate being able to locate free flowing bio-cells and trap them in our gripper.

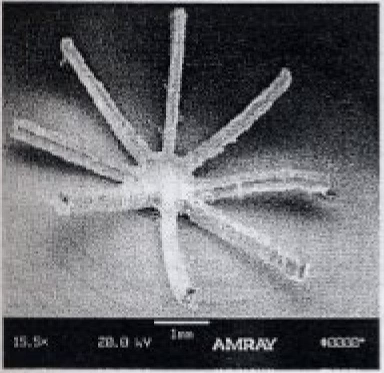

Figure 1. *SEM photo showing a laser-micromachined ICPF polymer film as a micro-gripper.*

Fabrication process

The development of ionic polymer-metal composites actuators requires an interdisciplinary study in chemistry, materials science, controls, and robotics. Mechanisms such as micro-end-effectors, grippers and micro-robotic-arms involved great deflection and have unique design and fabrication challenges. Currently, we are concentrating on developing a feasible system using a relatively simple and IC compatible fabricating technique. Recent processing advancements and comparison with other methods are reported in this paper. Basically, since Nafion films have a fluorinated structure, the poor surface adhesion of any coating has become an obstacle in making controllable and stable actuators. Metal deposited on the polymer surface will easily crack and peel off if there is no appropriate surface pre-treatment. Some researchers reported workable solutions using a chemical etchant (Tetra-etch®) [4] to etch the surface or to introduce a seed layer between the metal and the polymer. We have tried using chromium, platinum and silver coated compounds as a seed layer, however, due to the residual stress between the different materials (the seed layer and the gold electrodes), cracks appeared on the metal film as shown in Figure 2. Peel-off of the deposited metal is even worse if cracks exist, which led us to shift to another alternative.

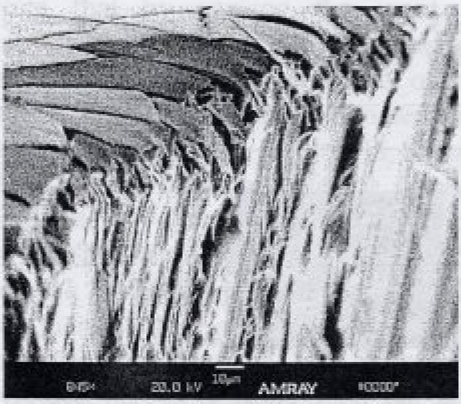

Figure 2. *SEM photo showing cracks due to residual stress between seed layer (film of Cr) and film of Au on the polymer surface.*

Our solution uses different deposition techniques to do the coating without the aid of any seed layer. For practical feasibility, it has become a prerequisite to have a reliable fabrication process. Nafion 117 is originally a perfluorosulfonic acid polymer film. First, the Nafion is roughed by fine sand paper (class 1500). Then we cleaned the sample pieces with HCL to remove impurities, followed by a deionized water rinse. Since coating to the fluorinated structure of the Nafion polymer surface is rather difficult, in order to maintain good adhesion, a thin film (about 0.5μm) of gold is firstly deposited on both sides of the polymer film using E-Beam evaporation. Then we coated a thick film (about 2μm) of gold by chemical electroplating. A satisfactory adhesion is achieved base on the above fabrication procedures (Figure 3). The gold-polymer composites can withstand a high voltage (20V) without peeling off.

An interferometer image of the actuator shown in Figure 1 and measured cross section is given in Figure 4 below and is used to verify the exact width of the gripper and study the surface roughness.

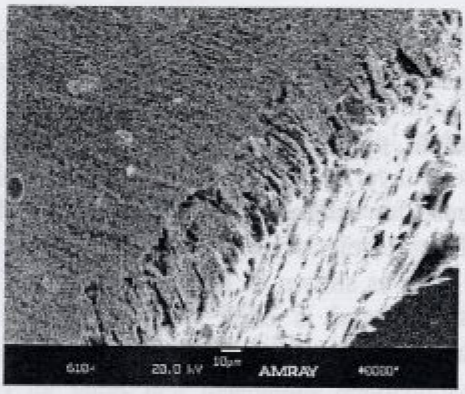

Figure 3. *Au thin film with good adhesion on the surface of Nafion 117 polymer film.*

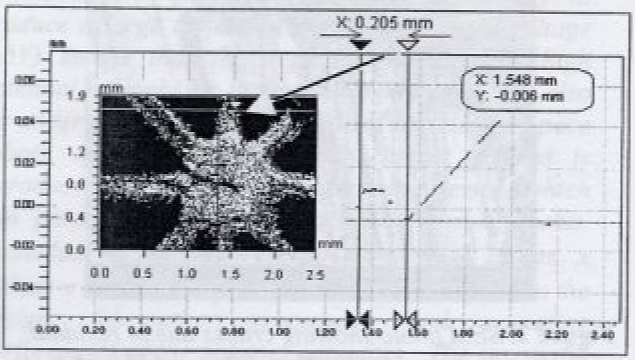

Figure 4. *Interferometer image on laser-machined micro-gripper with actuator leg width of 0.2mm.*

In order to ascertain the material properties of this special type of ionic metal polymer composites, a Young's modulus analysis and surface resistivity test were carried out. As shown in Figure 5, we use a strip of ICPF (2mm x 12.5mm x 180µm) as a cantilever beam and we added tiny masses (weight per each mass = 7.4x 10^{-3}g) at the tip of the cantilever and measure the deflection of the beam due to these changes in loading. Instead of using a laser displacement sensor [3], we introduce an image-monitoring device to capture real time deflection. Using the on screen scale, we can calibrate the Young's modulus of the ICPF film. The linearity between the loading and the deflection of the beam, which obeys Hooke's law, is shown in Figure 6. Based on this relation, we calculated the Young Modulus using a typical cantilever bending equation and the calculated moment of inertia of a beam. Referring to Figure 7, the measured Young Modulus of the ICPF film has an average value of 9.98 x10^7 N/m^2.

The surface resistance of the metal composites will greatly affect the performance of the actuator because the electrical voltage input will change the mobility of the cations. In order to minimize the input voltage for a particular actuating device, data from a surface resistance test is necessary. Three assumptions are necessary to make these measurements. First, we assume that the coated gold thin film has a constant cross sectional area. Second, we assume that any temperature effects can be neglected and third, only relative surface resistances are measured. A 0.2mm step up measuring system is to find out the surface resistance.

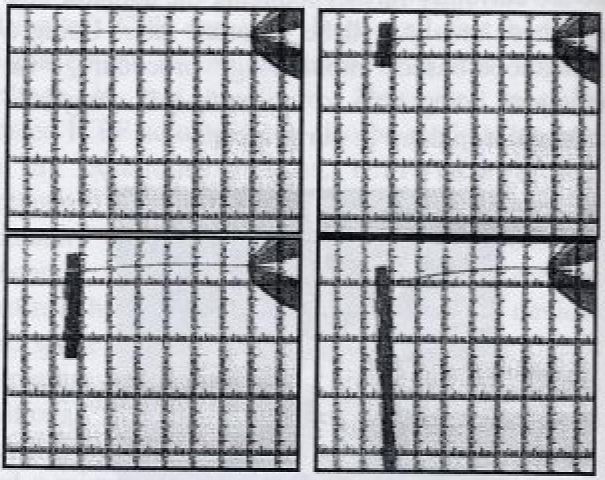

Figure 5. *Sequence of images showing the method to calibrate the Young's modulus of ICPF film using cantilever beam test approach.*

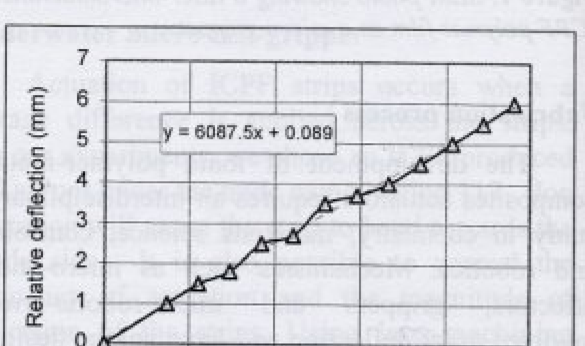

Figure 6. *Experimental results of the relative deflection to loading.*

As observed through a microscope, by stepping up the difference between the 2 micro-probes by 0.2mm per move, we observed difference resistance readings. Figure 8 shows the comparison of the surface resistance from calculation and from measurement (which has a consistent 1Ω increase in resistance with every 3mm increase in the distance between the probes).

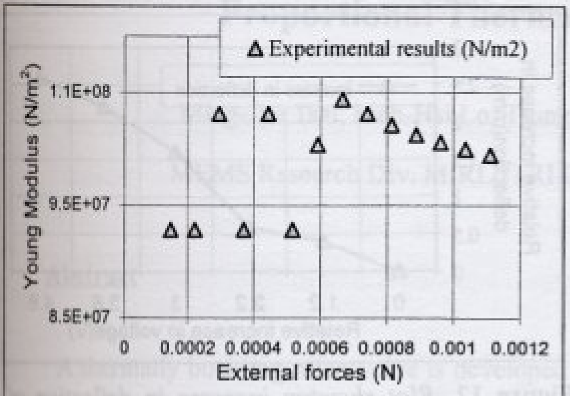

Figure 7. *Experimental measurement of the Young's modulus of ICPF film.*

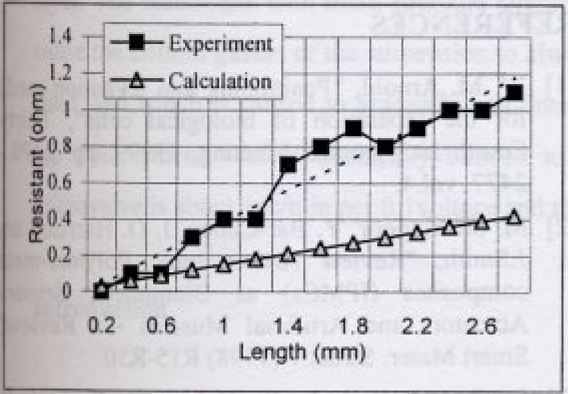

Figure 8. *The theoretical calculation for the thin Au film resistance is given and is compared with experimental measurement of surface resistance (~1Ω increase with 3mm increase in length of 2 probes).*

Actuation scheme

A strip of ionic conducting polymer composites can give a large bending deflection when an electric field is applied across the electrodes. A typical ICPF bending test is carried out by using the measurement system outlined in Figure 9. This system is capable of observing actuation and recording deflection of the strip in real time. A transparent distance scale with resolution of 200μm is placed in front of the image-monitoring device and we use a clamp to hold the strip as well as to serve as the anode and cathode.

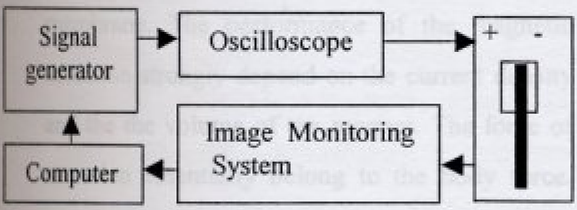

Figure 9. *Deflection measurement setup using image monitoring system.*

In Figure 10, we observed >4mm deflection with a maximum bending angle of 90° towards the anode side when a square input signal of 5V is applied. Using the function generator, we can adjust the frequency response of the metal polymer composites as well as the input voltage magnitude that allows us to control the deflection. We are currently working to optimize the geometry so that for an input voltage to 2V, it will be possible to get a frequency response of 1 Hz. Note that by varying the input signal frequency, we can adjust the frequency of the bending moment, which means control of the rate of actuation. However, the deflection decreases as the frequency increases. Figure 11 shows the deflection of the strip in different frequencies with a constant voltage input (7V). When the input signal frequency is 0.3Hz, there is a 3mm peak-to-peak deflection of the strip. However, when we increase the frequency to 1.95Hz, only a 0.4mm deflection is noticed. This is because the input voltage period is faster then the actuator response time. The strip will switch bending direction without reaching the max bending position.

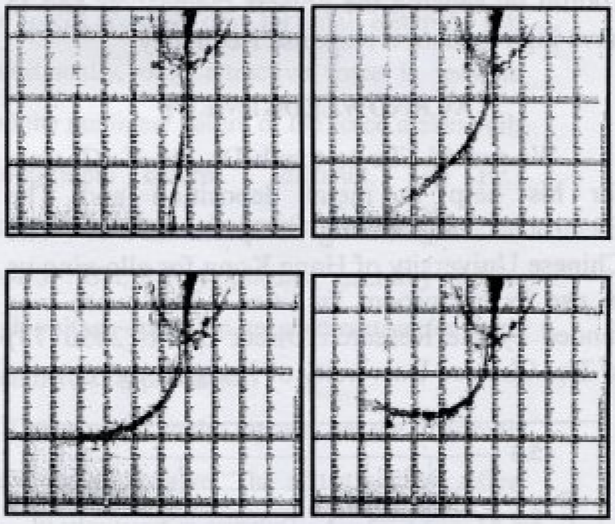

Figure 10. *Sequence of photos showing a typical under water bending deflection test. More then 6mm deflection is recorded.*

Apart from the frequency response, the magnitude of the deflection is also another key factor affecting the performance of all types of ICPF actuators. Figure 12 shows the result of the increase in deflection of a sample ICPF strip with a width of 1mm, and a length of 8mm, when the applied voltage is increased relative to an initial voltage input and deflection. Referring to the figure, we can see that there will be a 2.5mm increase in deflection if the input voltage is increased approximately by 4V.

Conclusion

We have successfully created an ICPF composite using Nafion sandwiched by gold electrodes. We have overcome the adhesion problem between gold and perfluorosulfonic acid polymer film through a novel processing procedure. Also we have developed a new approach to reliably and simply fabricate metal polymer composites. In addition, underwater micro-grippers with 0.2mm strip leg widths were fabricated using a laser-machining process. There is plenty of room to decrease the voltage consumed as long as it is not necessary to increase the frequency response of the gripper. We will concentrate on this for future experiments. In parallel, we are also investigating the possibility of integrating the control design and actuator. A feedback controlled gripper with self-triggered actuation technique will be developed later. Our goal is to minimize the gripper to grasp bio-objects with sizes less than 100μm by sensing the objects themselves and to have high actuation response frequency.

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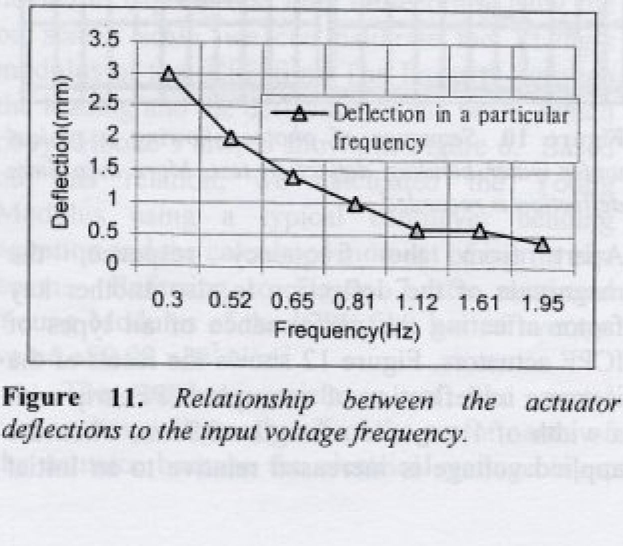

Figure 11. *Relationship between the actuator deflections to the input voltage frequency.*

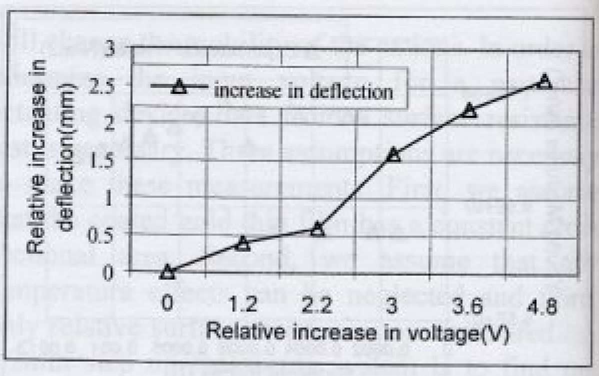

Figure 12. *Plot showing increase in deflection of a sample ICPF strip to the increase in input voltage relative to an off-set voltage.*

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