The Study of Shape Memory Ionic Polymer-Metal Composite Actuator

By: Liya Napollion, Qi Shen,

Mentor/Advisor: Dr. Kwang J. Kim

Active Materials and Smart Living (AMSL) Laboratory, Department of Mechanical Engineering

Overview

- In recent years, shape memory polymers have drawn greater interest for applications such as smart fabrics, intelligent medical devices, adaptive aircraft structures, adaptive space structures, morphing structures, and packaging. Development of biomimetic actuators has been an important motivation in the study of smart materials. Nevertheless, few materials are capable of controlling oscillating and bending deformations simultaneously or separately.
- A soft multiple-shape-memory electroactive polymer (EAP) called Ionic Polymer-Metal Composite (IPMC) actuator is presented and experimentally demonstrated in this study. IPMC actuator having multiple-shape memory effect (MSME), is able to perform complex motions by two external inputs: electrical and thermal. The MSME of a star shaped polymer using Aquivion (to mimic the nastic movements of a flower) was conducted in this study to show that Aquivion displays great MSME.
- The demonstration of shape memory effects in ionic polymer actuators will add a new dimension to the use of smart materials and constitutes an important consideration when operating such actuators in environments where temperature changes.

Introduction

- IPMCs are electroactive polymers that show a large strain and prompt response under low driving voltages. It consists of an ion exchange polymer film and two conducting materials as electrodes. When an electrical potential is applied to the metal electrodes, the hydrated mobile ions in the ion-exchange membrane migrate by means of electrostatic force, resulting in the actuation of the IPMCs [1].
- The promising properties shown by IPMCs suggest their application as biomimetic actuators for artificial muscles.

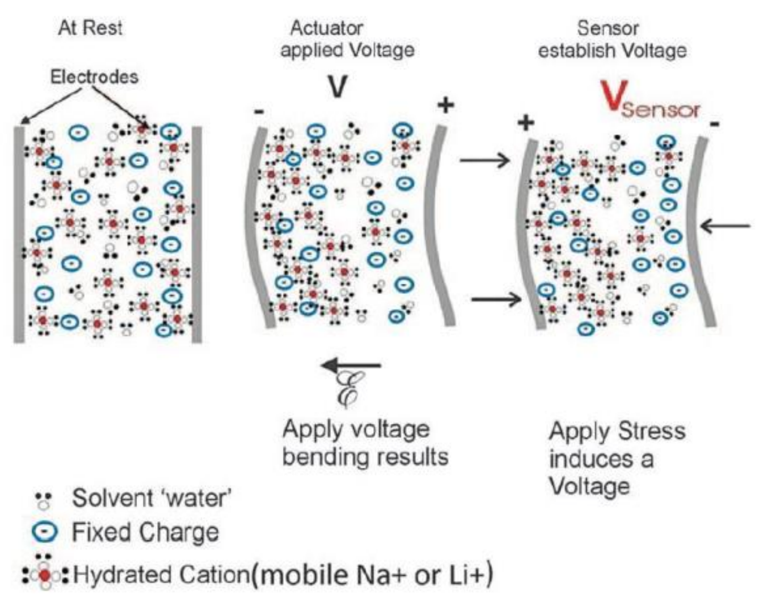


Figure1 : Actuating mechanism in IPMC [2]

- Shape memory polymers are materials that memorize a permanent shape and return to their original shape under specific conditions of external thermal, electrical, or other stimulations. Compared to other shape memory materials, like shape memory alloys (SMAs) or shape memory ceramics (SMCs), shape memory polymers (SMPs) have desirable advantages such as **high elastic deformation** to enable large shape change, **broad tailorability** of mechanical properties, **potential biocompatibility** and **biodegradability**, **ductility**, **light weight,** and **ease of processing**.
- Aquivion membranes are used for electrochemical applications such as polymer electrolyte fuel cells, electro-deionization systems, ozone generators, water electrolyzers, hydrogen separators and compressors, and redox flow batteries.
- Aquivion has a broad glass transition temperature; therefore, it can be programmed with a large number of unique shapes.

Method

❖ **Fabrication of MSM-IPMC**:

- The fabrication process is broken into two steps: cleaning and plating.

❖ ***Cleaning***:

- Roughened the Aquivion membrane surfaces to even out the thickness of the membrane and increase the surface area for the platinum to impregnate.
- Cleaned the membrane with 3% Hydrogen peroxide (H_2O_2) to remove organic impurities, and 1M of sulfuric acid (H_2SO_4) to remove metallic impurities.

❖ ***Plating***:

- The impregnation step uses a platinum salt solution (Pt(NH_3) $4Cl_2 \cdot H_2O$). The membrane is left in solution for 3.5 hours.
- In the primary plating process, the membrane is bathed in sodium borohydride to plate the platinum onto the membrane. The primary plating process is repeated three times with a cleaning process following each.
- In the secondary plating process, the membrane is bathed in hydroxylamine hydrochloride ($H_2NOH \cdot HCl$) and hydrazine ($NH_2NH_2 \cdot H_2O$)
- The electrode surface resistance is measured following the secondary plating.
- Finally, the MSM-IPMC is then placed in a LiCl bath for 24 hours to reintroduce mobile cations (Li^+).

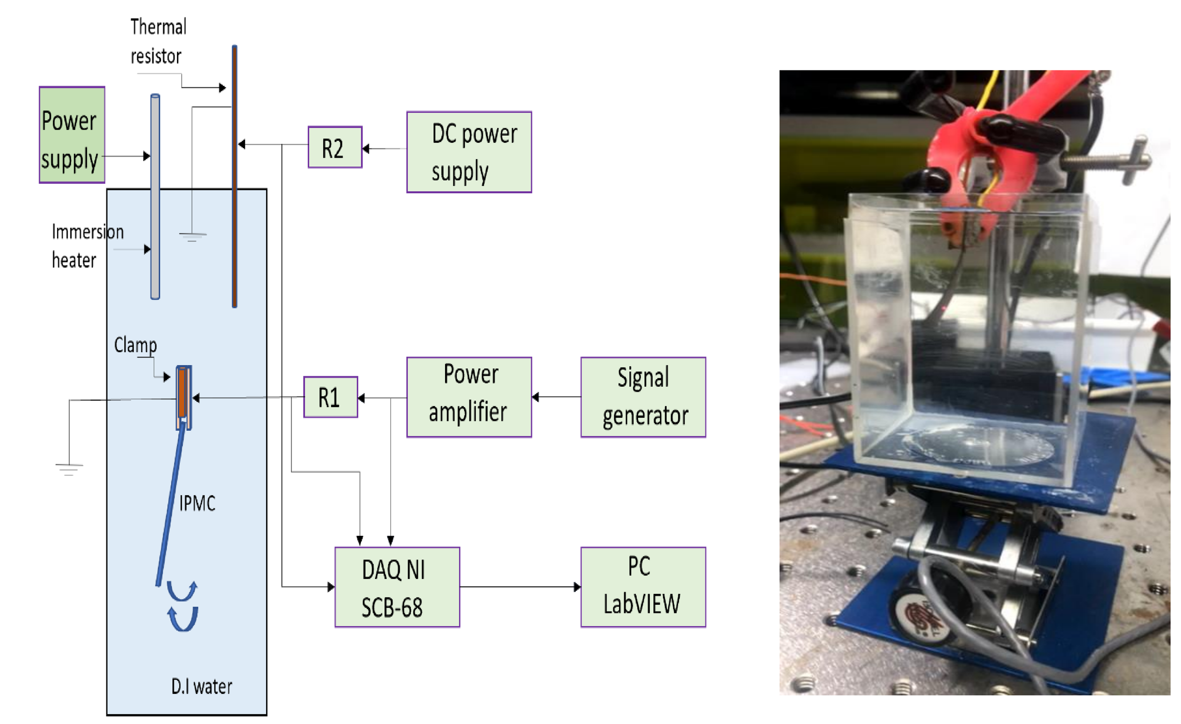
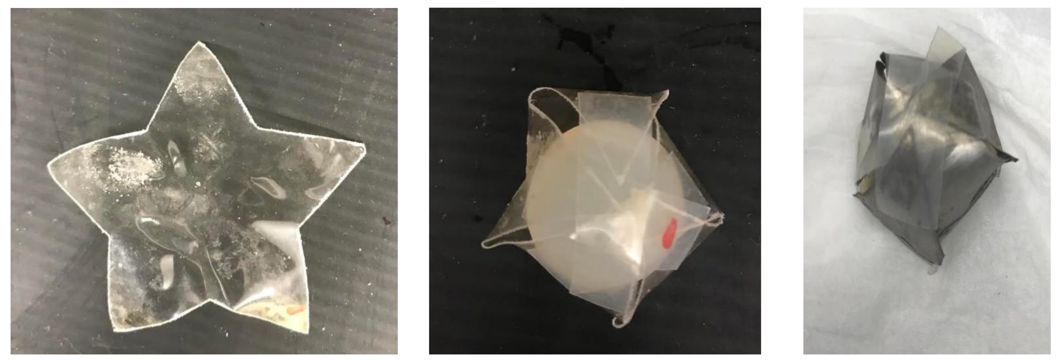


Figure 2: Experimental set up utilized for measuring thermal and electromechanical responses of IPMC and shape memory IPMC actuator

❖ **Shape programming of shape memory IPMC**:

- The desired shape of the shape memory IPMC was programmed and fixed prior to actuation. The Aquivion based IPMC would be programmed and tested in deionized water. To program and fix the shape, the Aquivion membrane was wrapped around a ball. The programing and fixing temperatures were 85 °C and 70 °C respectively. The shape was memorized within the temperature 85 °C and 70 °C. When the shape memory IPMC was reheated at 70 °C, it would recover the programmed shape through glass transition.



[a] **[b]** **[c]**

[d]

Figure 3: [a] A star shaped Aquivion membrane, [b] Wrapping the Aquivion membrane around a ball to be programmed, [c] Aquivion IPMC (plated with platinum) ready to be programmed. [d] Programming the Aquivion IPMC

Results

- Through the clamp contacts, a voltage input of 2V amplitude is applied to the sample. A laser sensor is used to measure the displacement of the sample. The voltage and displacement were measured simultaneously through the DAQ NI SCB-68 and were recorded using the LabVIEW software. It can be seen that the IPMC performed a large bending motion (about 7.5mm peak to peak).

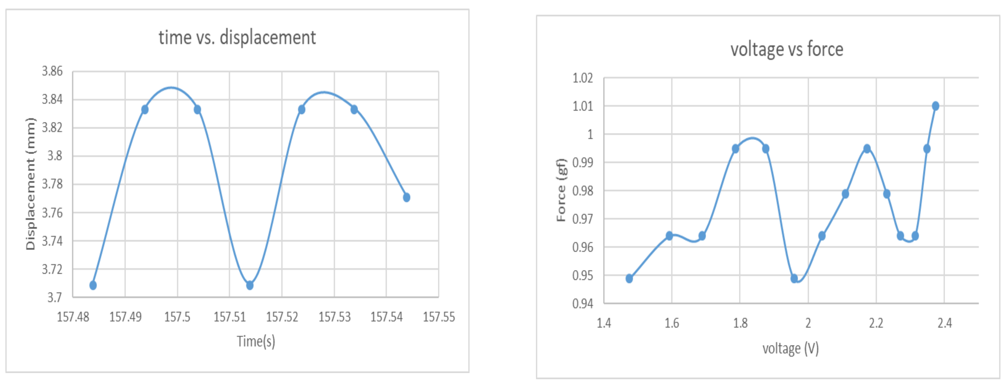
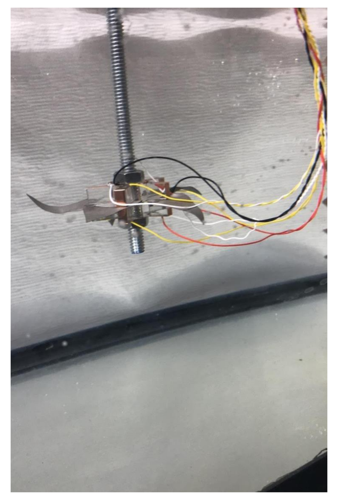


Figure 4: Measured displacement and voltage of the Aquivion based IPMC.



- The student is currently testing the oscillating and bending motions of a starfish locomotion which require movement of one arm at a time.
- The bending motions is induced thermally and oscillating motion is induced electrically.

Figure 5: Testing the star shaped Aquivion based IPMC

Conclusions

- It has been demonstrated that Aquivion based IPMC has significant shape memory effects. The shape memory effect of the ionic membranes used in this study likely results from the molecule chain motion of the membrane. The result shows two essential consequences:
  - Shape memory effects can be used to enhance the range and sophistication of IPMC actuators, and
  - These shape memory effects will change the actuation response with temperature and these must therefore be taken into account when IPMCs are used in applications where the temperature changes.
- The shape memory effects demonstrated in study are extremely attractive for new applications of ionic actuators, from micro-MEMs devices to larger artificial muscles.

Future Work

- Future work will investigate the relationship between chemical and mechanical structures and actuation mechanisms of Aquivion and Nafion based ionic polymers and the shape memory properties presented here.

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Reference

[1] Wang, H. S., Cho, J., Song, D. S., Jang, J. H., Jho, J. Y., & Park, J. H. (2017). High-Performance Electroactive Polymer Actuators Based on Ultrathick Ionic Polymer-Metal Composites with Nanodispersed Metal Electrodes. *ACS Applied Materials and Interfaces*, 9(26), 21998–22005.

[2] Yuan O. (2016). *Muscle-Alike Actuator Based on Ionic Polymer Metal*.