Electroactive Polymer for Flexible Energy Storage

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Goal/Motivation

- The motivation of this research was based on the features of IPMCs compared to conventional storage devices which includes flexibility, robustness, and small sizes and weight.
  - These characteristics put the IPMC materials ideal candidates for replacing conventional capacitors in different applications.
- The primary goal of this study is to explore the electrochemical characteristics of Nafion based Pt-IPMCs in capacitor systems.
- This development may improve the energy and power density compared to electrolytes as well as the quick charge-discharge capability.

Objectives

- To design the shape and structure of the flexible capacitors
- To manufacture flexible capacitors using low-cost materials
- To characterize the electrochemical performance and flexibility of the capacitors
- To study the electrochemical performance of flexible capacitors under mechanical testing conditions
- To improve and optimize the electrochemical performance and manufacture process of flexible capacitors

Introduction

- IPMCs are a type of electroactive polymers (EAPs) that have become important in the study of actuators and sensors.
- IPMC material that is consist of perfluorinated ion-exchange polymer (ex: Nafion) is plated on both sides with noble metal such as Pt or Au electrode layers.
- When voltage is applied across the electrodes, IPMC displays a large bending deformation[1].
- Conventional capacitors are restricted by size, shape, and typically must be wired directly to the circuit board. Such restrictions take up valuable space inside the electronic device packaging.

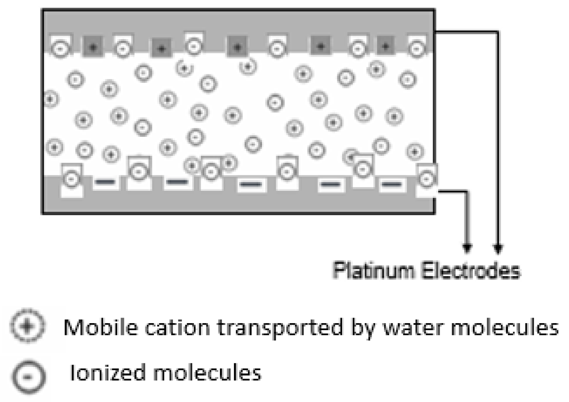


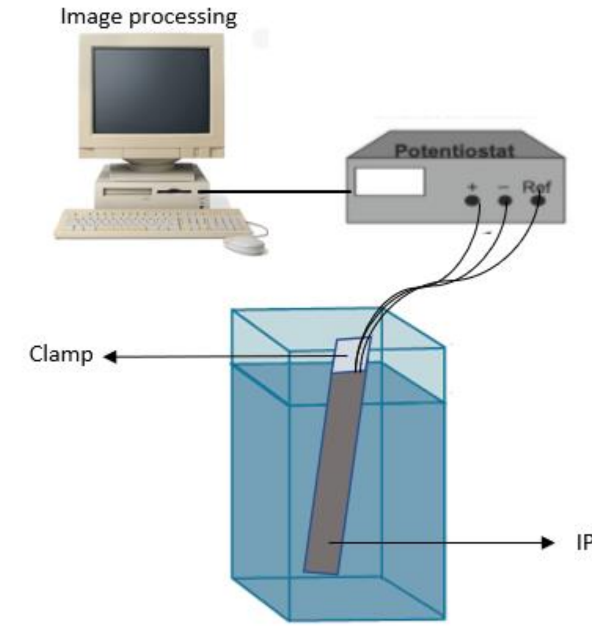
Figure1 : Surface IPMC(left) and drawing of a cross-section of IPMC (right)

- IPMC based capacitors can be fabricated to any planar shapes and sizes in order to meet the needs of specific applications.
- IPMCs display capacitive properties once they are placed in an ionic solution.
- The thickness of the polymer is at micron level; therefore, it significantly reduces the weight of the cell and allow systems to be lighter, safer, and flexible
- IPMCs for electrical storage application will produce results could enable individuals to design an efficient device that is durable.

Method

❖ **IPMC Sample Preparation: Electroless Plating**

- The Polymer strips ere obtained from a sheet of Nafion 117 with a thickness of 183 μm
- The fabrication of IPMC starts with surface roughening of the membrane, which is done by mild sand blasting followed by washing it with DI water respectively
- Ion-exchange (adsorption) is proceeded by preparing platinum complex ($[Pt(NH_3)_4]Cl_2$ or $[Pt(NH_3)_6Cl_4]$ and immersing membrane in the solution and leaving the membrane at room temperature for a day.
- The membrane is rinsed at 40°C and sodium borohydride and ammonium hydroxide solution are added. $NaBH_4$ is added every 30 minutes for several times while gradually raising the temperature. A black layer of Pt particles are seen deposited on the surface of the membrane.
- A very small amount of platinum is deposited by the primary plating, thus, to improve the sample's properties, an additional amount of platinum is plated by secondary process on the deposited Pt layer.
- Lastly, at 50 °C a 5% aqueous solution of hydroxylamine hydrochloride (NH_2OH-HCl) and 20% solution of hydrazine (NH_2NH_2) is added In the DI water that contains the membrane. Metallic layers will be formed on the membrane surface.



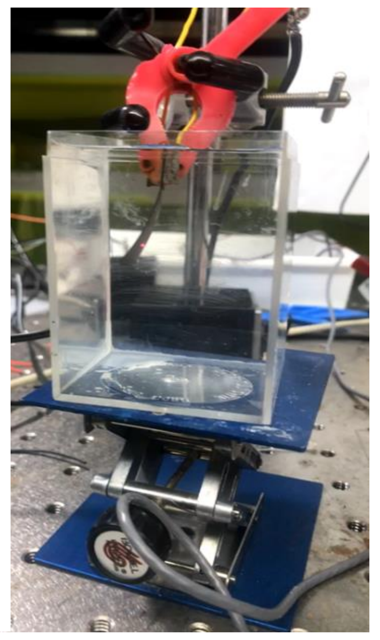
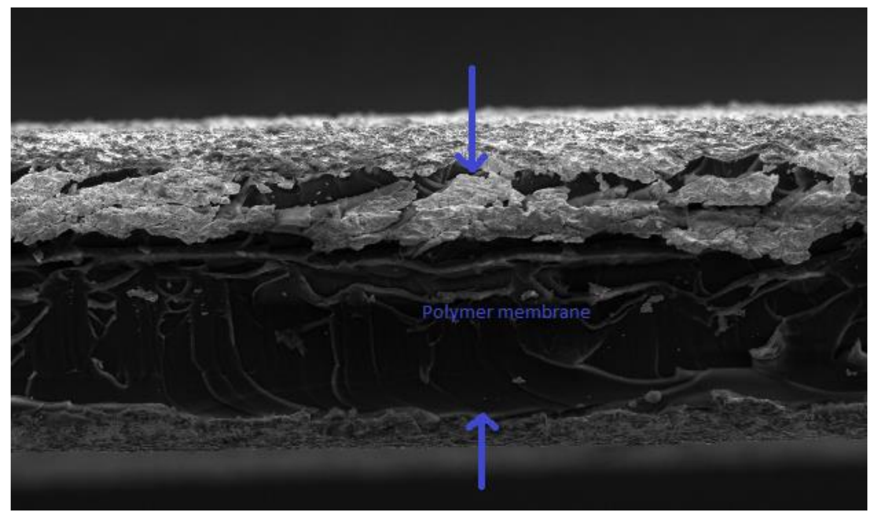


Figure 2: Schematic diagram of an experimental setup for electrochemical analyses

❖ **Experimental Setup**:

- Cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) measurements were conducted at ambient temperatures utilizing a Radiometer Analytical PGZ-402 potentiostat in a two-electrode configuration.
  - To investigate the electrochemical properties of Pt IPMCs
  - Measurements were performed in DI water
  - CV of the IPMC sample was recorded in a potential range of -0.25 to 1.2 V at a scan rate of 20 mV/s
  - Capacitance versus frequency plot is obtained from EIS measurements at a frequency range of 1kHz to 0.1HZ using an AC perturbation of 10mV.

Results



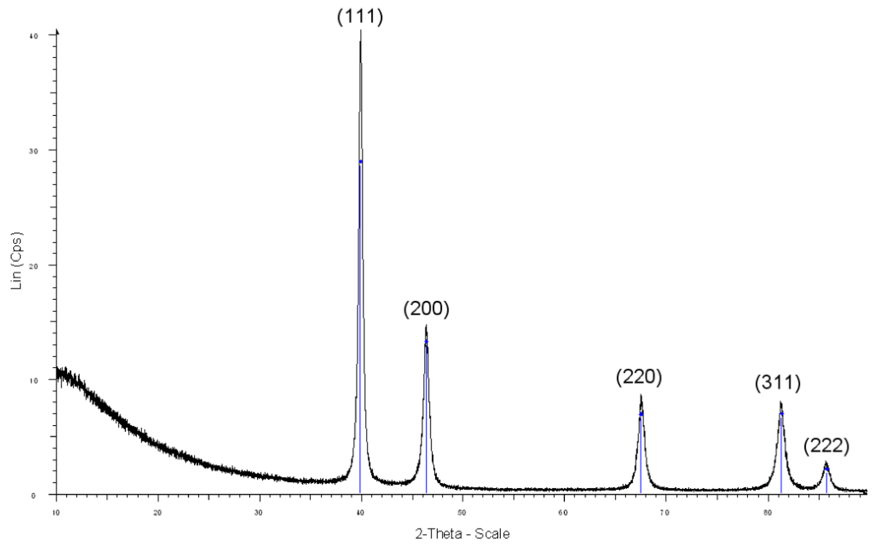
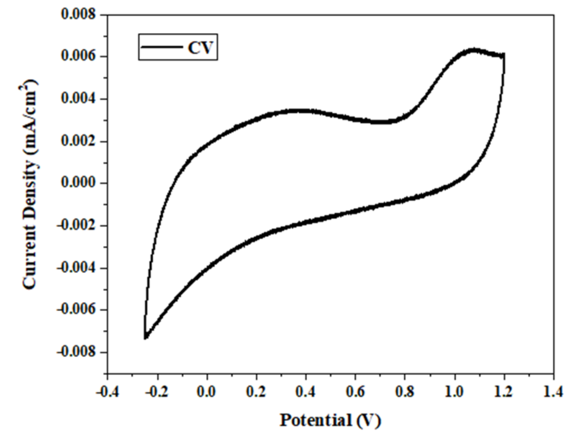
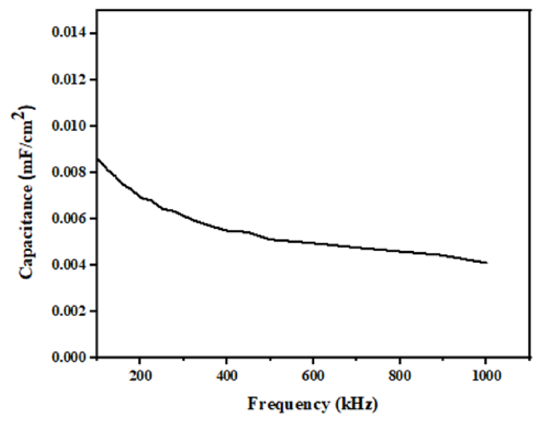


Figure 3: SEM image(Top) and x-ray pattern of the IPMC sample(bottom)

- A SEM is used to study the microstructure or characteristics of the electrodes.
- The IPMC strip contains distinct texture
  - This may be due to the poor control of the deposition of the electrodes on the surface of the polymer
  - Difference between electrode surface influence the physical behavior of the IPMC

- To examine the phase composition and structure of the sample, XRD analysis was carried out and the pattern is shown.
  - Found pure Face-Centered Cubic (FCC)
  - The Pt particles have penetrated deep into the polymer membrane
    - The Pt layer is used as a highly conductive current collector





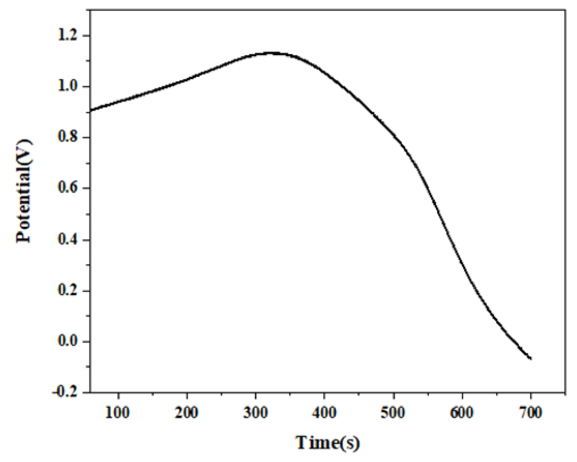


Figure 4: Cyclic voltammograms of Pt measured in DI water(top left), EIS capacitance of Pt as a function of frequency (top right), and capacitor discharge cycle (bottom left)

- The flat line displays the ionization of absorbed hydrogen at Pt electrodes. Starting from 1.0 V, the adsorption of oxygen takes place at the Pt electrodes.
- There's a difference between the peak potentials in oxidation and reduction curves which shows the irreversible nature of oxygen adsorption.
- Experimental tests showed the IPMC sample showed levels of capacitance of 6.42 mF/g . It is also shown that the capacitance of the IPMC increases at lower frequencies. The capacitance at 100kHz is $0.010 mF/cm^2$
- Under an input of 2mA the sample charge to 1.1V followed by initial discharge to 0.1V before leveling off

Conclusion

- It is shown that Pt based IPMC is capable of storing energy and further studies need to be conducted in order to investigate the electrochemistry characteristics of the material for different applications.

Acknowledgment

- This project was, in part, supported by the Nevada NASA Space Grant Consortium and National Science Foundation (#1545857). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and don not necessarily reflect the views of NSF.

Reference

[1] Kim, D., Kim, K. J., Nam, J. Do, & Palmre, V. (2011). Electro-chemical operation of ionic polymer-metal composites. *Sensors and Actuators, B: Chemical*, *155*(1), 106–113. https://doi.org/10.1016/j.snb.2010.11.032