Experimental Study on the Effect of Gold Thickness and Concentration of the Electrolyte Solution of Ionic Polymer-Metal Composites (IPMC)

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1- Introduction

Polymers that can be stimulated to change shape and size have been researched for many years. The convenience and the practicality of electrical stimulation, as well as improved capabilities, make electro active polymers (EAP) one of the most attractive among polymers with the capability of being activated. One class of EAP's are conjugated polymers, which are also called conducting polymers or synthetic metals.

Conjugated polymer actuators require a low actuation voltage (less than 1 V), generate considerable stress and large strain outputs, and are light and biocompatible. These advantages make them attractive for a wide range of robotic and biomedical applications, such as micro- and bio manipulation, biomimetic systems, and biomedical devices.

The purpose of this research is to build and evaluate the behavior and properties of an ionic polymer-metal composite (IPMC). Thus, a polymer coating on a metal ion is created and the microscopic structure of the interface has been studied. Also, the important parameters and the optimal conditions for the construction of an IPMC have been investigated.

2- Experimental procedure

Multi-layer EAP actuators prepared by separating two electro active polymer (PPy) films by an insulating soft, porous film (PVDF) and containing the electrolyte within the internal pores can operate both in dry and wet environments. These materials involve the mobility or diffusion of ions and consist of two electrodes and electrolytes.

Propylene carbonate (PC, Merck), lithium triflouromethanesulfonimide (LiTFSi) from Sigma−Aldrich were used in the as-received condition. Pyrrole (Merck) was distilled and stored under nitrogen at −20 ◦C before use. HV type filter membrane (Millipore) of 0.45 μm pore size and 75% porosity was chosen as a backing material for the fabrication of the electromechanical actuators. The thickness of the PVDF porous membrane was 110 μm and it was sputter coated with a thin layer of gold. Gold sputtering was carried out on both sides of the PVDF membrane using a Desk Sputtering coater DSR1, at 2×10^{-3} mbar pressure and 25 mA current.

Fabrication of the tri-layer conducting polymer is achieved by electrochemically oxidizing the pyrrole monomer from a solution to grow PPy layers on either side of a gold-coated porous PVDF film, which acts as the working electrode.

The coated layers of gold serve to provide a conductive surface. The gold layer is porous and allows contact between the PPy and the electrolyte solution contained within the PVDF film.

The polypyrrole layer is shown in Fig. 1. The developed electroplating sits on a gold coating through an electrolyte solution method.

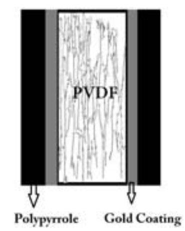

Fig. 1 A schematic of the structure of the ionic polymer-metal composite (IPMC)

Electroplating was used for the electrochemical deposition of polypyrrole. According to Fig. 2, after preparing the electrolyte solution, it is placed inside a container. By using dry ice around the solution container, the required temperature is set. The PVDF components (working electrodes) are also covered with gold, and two stainless steel reference electrodes were also chosen.

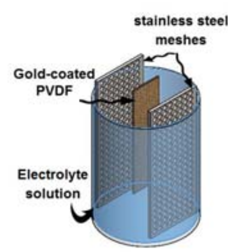

Fig. 2 Schematic of the jar containing the working electrode, the electrolyte solution and electrode counter

The various parameters for the 3 samples are shown in Table 1.

Table 1 Conditions of the three samples

Sample	Gold-coating (min)	Concentration of electrolyte (molar)	Deposition temperature (°C)	Deposition time (h)
1	3.5	0.1	-20 to -25	4
2	4.5	0.1	-20 to -25	4
3	3.5	0.05	-20 to -25	4

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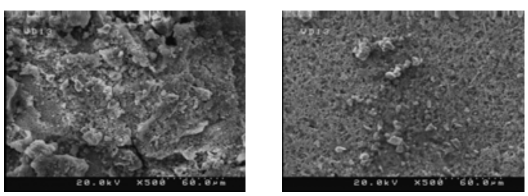
After polymerization, the actuators were rinsed with acetone and soaked with a 0.1 M LiTFSI/PC solution. The conductive polymers were characterized by FTIR and scanning electron microscopy (SEM) techniques.

3- Results and discussion

The concentration of pyrrole and salt in the electrolyte solution are two of the main factors in electroplating-deposition. The effect of the concentration of pyrrole and salt on polypyrrole deposition with different concentrations (0.1 and 0.05 M) was studied using spectroscopic and SEM microscopic images, as shown in Table 2 and Fig. 3.

Table 2 Comparison of the solution concentration in the samples

Sample	Gold-coating (min)	Concentration of electrolyte (molar)	Deposition temperature (° C)	Deposition time (h)
1	3.5	0.1	-20 to -25	4
3	3.5	0.05	-20 to -25	4



(a) (b)

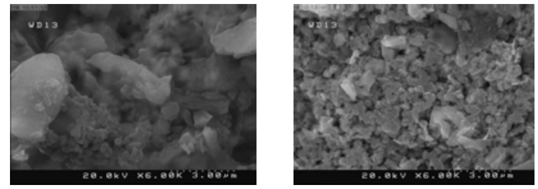
Fig. 3 SEM micrograph of (a) sample 1 and (b) sample 3

According to the SEM images in Fig. 3, polypyrrole layers on gold-coated PVDF polymer can be observed. The polypyrrole layer in sample 1 is denser than that of sample 3, because the concentration of electrolyte solution in sample 3 is lower and there are more porous structures observed in the sample. The coating thickness for sample 1 is about 12 microns and for sample 3 it is about 10 microns (Fig. 3). Thus, the density and thickness of the polypyrrole coating increased by increasing the concentration of pyrrole and salt in the electrolyte solution.

The substrate can affect the structure of the shared surface between electrode-electrolyte. The polypyrrole layer sits on a layer of gold. Two different gold thicknesses were created by sputtering, as shown in Table 3. Fig. 4 shows microscopic images of the corresponding samples.

Table 3 Comparison of the gold coating thickness 0.1 M in the samples

Sample	Gold-coating (min)	Concentration of electrolyte (molar)	Deposition temperature (° C)	Deposition time (h)
1	3.5	0.1	-20 to -25	4
2	4.5	0.1	-20 to -25	4



(a) (b)

Fig. 4 SEM image of the cross section of (a) sample 1 and (b) sample 2

According to Fig. 4, by increasing the thickness of the gold coating, the electrical resistance of the polymer is reduced, the increased potential decreases the current density and prevents the appearance of surface roughness and hence, the surface become more uniform.

4- Conclusions

In this research, a multi-layer conductive polymer was built and thin films were synthesized. The polymerization parameters were investigated and the results were compared. It was concluded that the electrolyte concentration of 0.1 M has a better impact on the structure of the polypyrrole coating. The reason for this is that by increasing the concentration of the solution, the percent of pyrrole and LiTFSi/PC increased, resulting in a more uniform coating and lower cavity creation. In addition, by increasing the thickness of the gold layer, the electrical resistance decreased, leading to an increase in the electrical potential; thus the surface become more uniform.