Improvement of manufacture technology and research of actuators based on ionic polymer-metal composites

I K Khmelnitskiy, L O Vereshagina, V E Kalyonov, A P Broyko, A V Lagosh, V V Luchinin and D O Testov

Research and Education Center "Nanotechnologies", Saint Petersburg Electrotechnical University “LETI”, 197376, Saint Petersburg, Russia Federation

E-mail: khmelnitskiy@gmail.com

Abstract. The purpose of this work is to improve the operational characteristics of actuators based on ionic polymer-metal composites (IPMC) by improving their manufacture technology. The optimal thickness of the ion-exchange membrane was determined. The technology of metal electrode deposition, the composition of actuator electrolyte solution and the storage method of actuators were optimized.

The creation of power-efficient, inexpensive actuators and micro robotic systems based on them made by micro- and nanosystem technology is an actual problem [1].

Recently, special attention is paid to actuators based on IPMC, due to its low driving voltage and large deflections [2]. Ionic polymer-metal composite (IPMC) is synthetic composite nanomaterial that consists of ion-exchange polymer coated with a conductive metal. Mechanical deformation of the actuator is caused by the applied electric field. And on the contrary, mechanical deformation of the membrane induces electrical signal. So, IPMC actuator could be used as sensor and as actuator. The operation actuator parameters depend on many factors [3–5].

The principle of IPMC actuator operation is following. After applying of external electric field, ions of the same charge begin to move from the anode to the cathode. So, this electroosmotic fluid flow results in excessive fluid pressure near an electrode. Thus, the actuator deformation is caused by the pressure difference between the upper and bottom electrodes [5] (figure 1).

The purpose of this work is to improve the operational characteristics of IPMC actuators by improving their manufacture technology. So, it was necessary to solve the following tasks for attainment of this object: the choice of an optimal thickness of the ion-exchange membrane, the technology improvement of metal electrode deposition, the selection of a proper actuator electrolyte solution and the research of storage methods for actuators.

The thickness of the commercially available Nafion® film varies from 50 to 180 μm. The efficiency of IPMC actuators changes with the thickness because some parameters such as bending stiffness, driving voltage, etc., depend on the thickness value.

When one’s chooses a thickness of actuator membrane the crucial parameters are the developed force and the created displacement. The actuator made of the membrane with a thickness 175 μm develops larger force than the one made of the membrane with a thickness 50 μm (figure 2), but the values of displacement are similar for both (figure 3). Thus, the membrane with a thickness of 175 μm was chosen for further investigations.
In order to reduce a driving voltage and increase the transformer effectivity, it is necessary to produce wear-resistant, flexible and high conductive electrodes on the membrane surface. One of most effective methods for electrode manufacturing is deposition by chemical reduction from a platinum solution. This process consists of two steps. At first, platinum particles are precipitated in the near-surface layer. Next, platinum electrodes are deposited directly on the membrane.

During the first step, membrane is soaked in salt solution of tetraammineplatinum chloride Pt(NH₃)₄Cl₂. Thus, cations containing platinum diffuse into the membrane by ion-exchange process. Then, platinum is deposited by reduction with sodium borohydride NaBH₄ solution. Highly dispersed metal layer is formed inside the membrane.

At the second stage, platinum precipitates from the solution, containing a platinum salt Pt(NH₃)₄Cl₂, hydrazine H₂NNH₂ and hydroxylamine NH₂OH. Thus, the electrode thickness on the surface increases. Decrease of electrode resistance could be obtained by the thickness increase of the deposited platinum layer. This could be achieved by repeating the second stage twice.

The samples of actuator were produced with electrodes deposited on the membrane by three methods:
- the first method: apply the first and then the second stage (1 + 2).
- the second method: repeat first stage twice and then the second once (1×2 + 2).
- the third method: apply the first and then the second stages, each twice (1×2 + 2×2).
The focused ion beam method (Helios NanoLab 400 FIB station) was used to investigate the IPMC structure. Sample sections of IPMC actuator were obtained by the focused ion beam (figure 4(a)). In the figure 4(a) one can see two layers of the platinum particles which differ in morphology. The bottom layer – diffusive, obtained at the first step of platinum deposition process when the platinum particles penetrate into the membrane. Thickness of this layer for different samples varies from 6 to 10 µm and the sizes of the dispersed particles are within the range of 30–90 nm (figure 4(b)). The concentration of platinum particles gradually decreases with the increase of distance from membrane surface. The upper layer thickness obtained after additional platinum deposition at the second step depends on the time of deposition and the number of iteration. Thus, thickness varies from 2 to 10 µm. The layer consists of granular platinum particles with a size within the range of 40–60 nm (figure 4(c)).

![Figure 4. Images of IPMC actuator section obtained by FIB station: whole section (a), diffusive (b) and surface (c) platinum layers.](image)

The next step was to study the operational characteristics of actuator samples obtained by different electrode deposition methods. The largest thickness and the lowest resistance of platinum electrode layer were obtained by the third method. The maximum value of developed force is about 10 mN (figure 5). The highest displacement of 15 mm is shown by actuator produced by the second method (figure 6).

![Figure 5. Developed force vs. driving voltage for actuators based on IPMC with electrodes produced by different methods.](image)

![Figure 6. Created displacement vs. driving voltage for actuators based on IPMC with electrodes produced by different methods.](image)
The actuator characteristics depend on the electrolyte composition dissolved in water. And the nature of cations which freely move within the membrane play the key role. Therefore, the characteristics of actuators soaked with different salt solutions were investigated. The highest displacements (figure 7) and forces (figure 8) are observed for actuator soaked with 0.1M CuSO₄ solution.

![Figure 7](image1.png)  ![Figure 8](image2.png)

**Figure 7.** Developed force vs. driving voltage for actuators based on IPMC soaked with different electrolytes  
**Figure 8.** Created displacement vs. driving voltage for actuators based on IPMC soaked with different electrolytes.

The method of actuator storage between usage has a great influence on operational characteristics. The actuator storage in a dry mode is not acceptable, because the Nafion® membrane volume changes during drying and soaking, which can lead to a change in the electrode structure. Therefore, the actuator must be stored in solution. The characteristics deteriorate almost twofold, when the actuator is stored in a 0.1M CuSO₄ solution, and no more than 20 %, when it is stored in water.

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