

A novel fabrication of ionic polymer-metal composites (IPMC) actuator with silver nano-powders

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Received 6 June 2005; accepted 13 November 2005

Available online 15 December 2005

Abstract

This article reports a novel approach of applying silver nano-powders to the fabrication of ionic polymer-metal composites (IPMC) actuator with good adhesion between the metal electrodes and polymer membrane without surface roughening pretreatment at low cost, high repeatability and short processing time. Micro-fabrication technologies are used for this IPMC actuator fabrication including the dissolving and casting of silver nano-particles (35 nm) in Nafion[®] diluted solution, followed embossing, nontoxic electroless plating of silver, and microelectroforming of nickel. This IPMC actuator exhibits large deformation of bending curvature angle of more than 90° at lower driving voltage of 3 V. The frequency response of displacement with applied AC voltage of 2 V at 1 Hz results in a regular periodic deformations of the IPMC actuator. The elasticity modulus of the IPMC actuator can be reduced using an Ag–Nafion electrode for larger deformation than a pure Ag metal electrode. The electronic active polymer, IPMC, could be potentially used as the actuator of the active guide-wire, effective biomimetic sensor and artificial muscles.
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Keywords: Ionic polymer-metal composites; Silver nano-powders; Actuator; Bio-MEMS

1. Introduction

An electronic active polymer, ionic polymer-metal composite (IPMC), could be developed into an actuator for the active guide-wire. This actuator generally consists of an electrical active polymer layer (Nafion[®] 20%) sandwiched by two metal electrodes. It is able to bend the curvature through electrical conduction and has two major advantages of larger deformation and lower driving voltage. When driving voltage is provided, the IPMC membrane will bend toward the anode direction because the hydrophilic positive ions move toward cathode [1]. Fig. 1(a) and (b) shows the structure of perfluorosulfonic acid membrane and the schematic diagram of the deformation mechanism of IPMC, respectively. The cations like Na⁺, Li⁺ and H⁺ in the IPMC actuator generally exhibit better bending performance than others [2].

The biological compatibility of the IPMC actuator is very good [3] and, thus, it is suitable for detecting or actuating in the human body. However, the adhesion between polymer and

electrode is a big problem during the fabrication of the IPMC actuator. To solve this problem, the electroless plating method had been used to fabricate the electrode layer, but it needed complex pretreatment to roughen the surface of polymer with high cost and time-consuming [4–6]. Therefore, other methods like hot-embossing, electroplating and polymer coating, etc. were provided for the adhesion promotion in decreasing the cost and time during fabrication [7–9]. Also, there are still some problems during the fabrication of IPMC, such as the inability to stay humid, and the difficulty of avoiding electrolysis at higher applied driving voltage (>1.23 V) [10,11].

In this paper, we propose a novel approach of integrating the physical and chemical methods for the fabrication of IPMC actuator without surface roughening pretreatment for good adhesion at low cost and short processing time. They include the silver nano-powders casting, embossing, silver electroless plating and nickel electroforming technologies.

2. Experimental details

IPMC actuators were fabricated using Nafion[®] solution produced by Du Pont Co. Ltd. The Nafion[®] is one kind of ion

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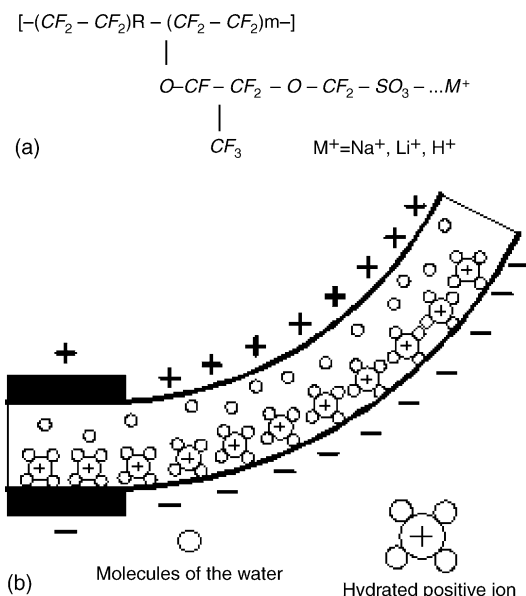


Fig. 1. (a) Structure of perfluorosulfonic acid membrane and (b) schematic diagram of the IPMC deformation.

exchange polymers, and the Nafion[®] 5 and 20% solutions were used to make the electrode and polymer membrane of IPMC actuator in this study.

2.1. Experimental procedures

The relationships between the spin speed and thickness of Nafion[®] 5 and 20% solution were calibrated first to understand how thick of IPMC membrane could be obtained. In the electrode fabrication, two kinds of the physical method were performed. One was the gold evaporated on the Nafion[®] membrane, and the other was casting the silver nano-powders on the Nafion[®] membrane. The evaporation of gold was carried out by the electron beam evaporator (HPS-510S, ULVAC, Taiwan Inc.) to a thickness of about 300 nm. To reduce the effect of the thermal stress between metal and polymer membrane, multi-step evaporation was used to control the temperature of the polymer membrane below 40 °C. The casting of silver nano-powders was one step of our novel process and described in the following.

Fig. 2 shows the novel process for fabricating the IPMC actuator with Ag nano-powders addition, including casting, embossing, Ag electroless plating and Ni electroforming steps. They are described in the following:

1. Using the diluted Nafion[®] solution to dissolve with silver nano-powders, and cast the solution with silver nano-powders (Ag–Nafion[®] 5%, 0.2 g/ml) on the glass for about 0.3 ml.
2. Casting the Nafion[®] 20% for about 1.5 ml on the electrode film to dissolve the solvent of the Nafion[®] solution. Thus, the excellent adhesion between the polymer and electrode films can be achieved. Baking the membrane with a two-step temperature of 60 and 100 °C.
3. Coating the adhesion layer and embossing the two structures to be one. Bake the whole IPMC actuator, and cool it down

- (1) Casting the silver powder membrane (Ag–Nafion[®] 5%, 0.2 g/ml)

- (2) Casting the Nafion[®] 20% about 1.5 ml

- (3) Coating a adhesion layer and embossing two structures

- (4) Electroless plating Ag to reduce the resistance

- (5) Electroforming of Ni to fabricate the contact pad

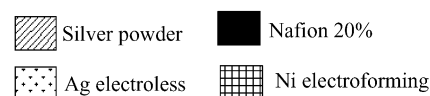
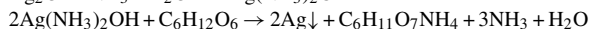
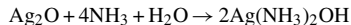
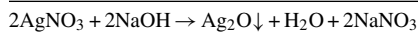


Fig. 2. The processing flow of IPMC actuator with Ag nano-powders.

Table 1

The electroless plating of Ag using silver nitrate and glucose reaction



at room temperature in order to remove membrane in water from the glass.

4. Electroless plating silver to reduce the resistance. First, clean the IPMC surface with a 0.5N sodium hydroxide (NaOH) solution. Then, perform the electroless plating of silver using silver nitrate (AgNO₃) and glucose (C₆H₁₂O₆) reaction listed in Table 1. The concentrations and doses of Ag electroless plating reaction as well as operation temperatures were listed in Table 2. The purpose of adding the ammonia water (NH₄OH) was to weaken the reduction of silver ion, and to form a complex with silver ammonium ion. Immersing the IPMC actuator into glucose and, then, putting it in the silver ammonium solution. Spontaneous redox reaction occurred in this process.
5. Electroforming of nickel metal to fabricate the contact pad. The operation conditions are listed in Table 3.

Table 2

The concentrations and doses of Ag electroless plating reaction as well as operation temperatures

	NaOH	AgNO ₃	NH ₄ OH	C ₆ H ₁₂ O ₆
Concentration (M)	0.5	0.6	15	0.1
Dose (ml)	30	25	1.2	35

Working temperature 70 °C.

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