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Bending direction of Ag-plated IPMC containing immobile anions and/or cations

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ABSTRACT

One of IPMCs, Ag-plated Selemion CMV containing $-SO_3H$ atomic groups, exhibited bending under a voltage. Its bending curvature heavily depended on the total charge given to it. The way in which the charge was given to Ag-plated Selemion CMV did not matter, as the bending curvature was always proportional to the charge quantity, as long as the environmental humidity was maintained constant. Such a proportionality was observed even for Ag-plated NEOSEPTA CMB containing $-SO_3H$ atomic groups. Even Ag-plated Selemion AMV and NEOSEPTA AHA both of which contained amino groups instead of $-SO_3H$ atomic groups bent in the same direction as Ag-plated Selemion CMV and NEOSEPTA CMB after long application of voltage. Furthermore, it was observed that Ag-plated amphoteric NEOSEPTA BP-1E containing both $-SO_3H$ and amino groups exhibited bending in the same direction as Ag-plated NEOSEPTA CMB. Hence, the sign of the charge of mobile and immobile ions contained in the ion exchange membrane did not appear to matter for determining the bending direction of IPMC. It was speculated that Ag layers played a central role for the bending induction of IPMC, and the ion exchange membrane per se must played primarily a role of current mediator and has almost nothing to do with determining the bending direction of IPMC.

1. Introduction

IPMC – ionic polymer-metal composite – is a bending mode actuator simply consisting of an ionic polymer film and metallic surface coatings [1]. It exhibits large bending upon a small applied voltage as small as a few volts.

One of IPMCs, Ag-plated Selemion CMV (Asahi Glass Co., Ltd.) containing the immobile atomic group of $-SO_3H$, exhibits a relatively well-controllable bending under an applied voltage, when it is in the largely dehydrated state [2–7]. Precisely speaking, Ag-plated Selemion CMV bending curvature is basically proportional to the total charge given to it. Only total current flowing through Ag-plated Selemion CMV body – total charge – determines the bending curvature, no matter how the charge is given to it. Such a property suggests that the control of charge given to Ag-plated Selemion CMV leads to the control of its bending curvature. It is a quite useful property for the purpose of fabricating a precisely controllable bending mode Ag-plated Selemion CMV actuator.

Current flowing through Ag-plated Selemion CMV has a particular characteristic. The current changes in accordance with the environmental humidity even under the same applied voltage [6,7]. Higher humidity causes the larger current, and it must be due to the more effective ionization of Selemion CMV body in the higher humidity environment [3,7]. However, irrespective of applied voltage or humidity, still only the total charge given to the Ag-plated Selemion CMV determines the bending curvature.

Occurrence of Ag-plated Selemion CMV bending was always accompanied by redox reaction of Ag layers on Ag-plated Selemion CMV surfaces [2–7]. Hence, the Ag redox reaction might be intimately related to that total charge, and Ag redox reaction might play a central role for the induction of bending. In fact, previously one of authors of this paper (H.T.) proposed a Ag-plated Selemion CMV bending mechanism based on the Ag redox reaction, where it associated the curvature with charge so that they could have a relationship of proportionality [4,7]. If that is actually true, the proportionality between curvature and charge observed for Ag-plated Selemion CMV could be observed even for other type of ion exchange membrane, as long as its surfaces are plated with Ag.

In this work, first we studied the bending properties of Ag-plated Selemion CMV so as to well understand the basic bending characteristics of Ag-plated Selemion CMV which one of the author of this paper (H.T.) had long studied. Next, it was investigated if the same bending properties as Ag-plated Selemion CMV were found in other type of ion exchange membranes. In the last place, we discussed the bending mechanism of Ag-plated ion exchange membranes.

2. Specimen preparation

First of all, the bending behavior of Ag-plated Selemion CMV was studied in this work. Then, other types of ion exchange

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membranes – Selemion AMV, NEOSEPTA CMB, NEOSEPTA AHA and NEOSEPTA BP-1E – were studied. All of the membranes were treated as below prior to testing their bending, where Selemions and NEOSEPTAs were manufactured by Asahi Glass Co., Ltd. and ASTOM Corp., respectively.

Surfaces of all ion exchange membranes were plated with Ag by the silver mirror reaction. On completion of Ag plating, the Ag-plated ion exchange membranes were washed with water and stored in the desiccator with desiccants in the vacuum state so as to be dehydrated [4].

3. Measurements

The curvature behavior of Ag-plated ion exchange membranes was studied under an applied voltage. The measurement procedure is explained taking up Ag-plated Selemion CMV as an example.

Ag-plated Selemion CMV sheet was cut into strips, 20 mm in length × 2 mm in width. A strip of Ag-plated Selemion CMV was horizontally clamped with electrodes on a jack as illustrated in Fig. 1. Voltage was applied to it, where the direction of positive for the voltage and current is shown in Fig. 1. The voltage polarity was maintained as depicted in Fig. 1 in all the measurements, it was never reversed. By using a laser displacement meter, the vertical tip displacement of Ag-plated Selemion CMV was measured as a function of time. Simultaneously, by using ampere meter, the current was measured as a function of time as well. Tip displacement was converted into the curvature, where the downward and upward bending was represented by the positive and negative curvature, respectively.

During conducting the measurements, the environmental temperature and humidity were under control, where all the measurements were conducted at 25 °C.

4. Results and discussion

4.1. Bending of Ag-plated Selemion CMV in various humidity conditions

The curvature behavior of Ag-plated Selemion CMV was studied under 1.5 V in three different humidity environment, 45%, 60%, and 75%. Fig. 2 shows dependence of Ag-plated Selemion CMV curvature on the total charge given to it. All the curves in Fig. 2 show the proportional relationship. Furthermore, all the curves are almost on the same line, where the charge in Fig. 2 represents the charge per 1-mm-width Ag-plated Selemion CMV strip (hereafter this definition is employed to represent the charge). However, the time dependence of current behaved differently in accordance with the humidity as shown in Fig. 3, where the current in Fig. 3 represents the current per 1-mm-width Ag-plated Selemion CMV strip (hereafter this definition is employed to represent the current). Hence, the way in which the charge was given to Ag-plated Selemion CMV did not matter for determining its curvature, only the total charge determined it.

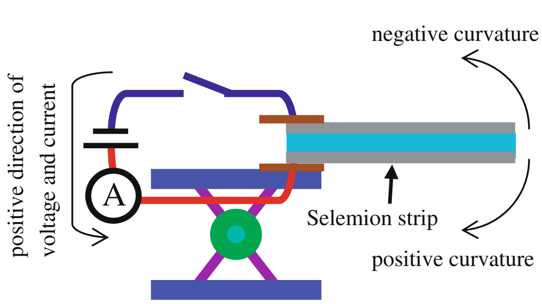

Fig. 1. Experimental setup for the measurement of IPMC curvature Direction of positive for voltage, current and bending curvature are shown.

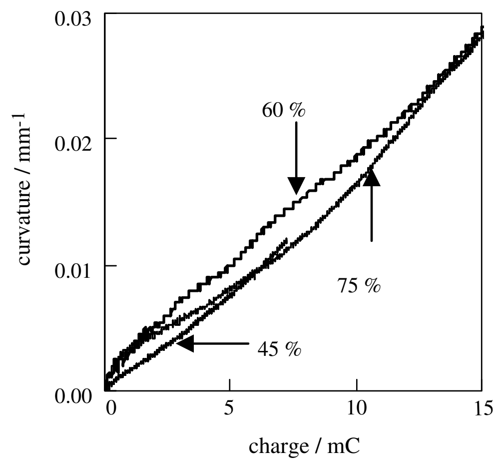

Fig. 2. Dependence of Ag-plated Selemion CMV curvature on the total charge given to it under 1.5 V in the environmental humidity, 45%, 60%, and 75%.

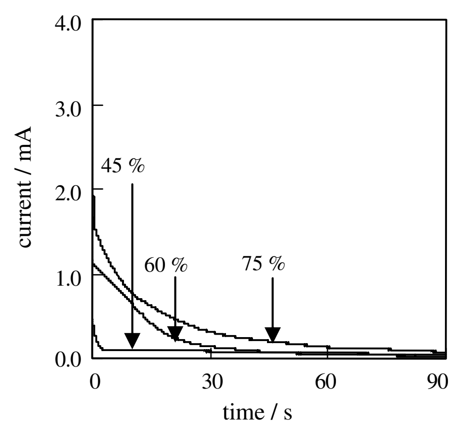

Fig. 3. Time dependence of current flowing Ag-plated Selemion CMV body under 1.5 V in the environmental humidity, 45%, 60%, and 75%.

4.2. Bending of Ag-plated Selemion CMV in N_2 gas

As described in Section 1, Ag-plated Selemion CMV bending accompanies redox reaction of Ag layers in its bending process. In fact, the color change of Ag-plated Selemion CMV surfaces which was due to the Ag redox reaction was observed in the experiments of the preceding section.

In this section, the bending tests of Ag-plated Selemion CMV were carried out under 1.5 V in N_2 gas environment with no O_2 gas in order to prevent the oxidation of Ag layer, where the humidity was 50% and 55%. Fig. 4 shows the proportional relationship between the curvature and charge. Even no O_2 around Ag-plated Selemion CMV, still bending was induced and the proportionality between the curvature and charge was maintained. Both curves in Fig. 4 are almost on the same line, despite the humidity difference. These curve behaviors are almost same as those shown in Fig. 2 even quantitatively. Hence, the existence of O_2 around Ag-plated Selemion CMV does not matter to its bending behavior. However, the color change of Ag-plated Selemion CMV surfaces by Ag redox reaction was actually observed in its bending process even in N_2 gas (no O_2) environment. Therefore, the occurrence of Ag redox reaction was inevitable for the induction of bending. O_2 involved in the oxidation of Ag in the N_2 gas environment must