



Development of an Adaptive Lens Using an Ionic Polymer-metal Composite

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ABSTRACT

The optical focus variable lenses have been widely used in consumer electronic devices to capture objects which are located in arbitrary position. These focus variable lenses are achieved by changing the distance between the two or more lenses or are made with electrowetting mechanism, liquid crystal material, or liquid with a pump. These lenses suffer from aberrations due to non-uniformities in the electric field and trouble with liquid evaporation. Another drawback of these focus variable lenses is to need an external mechanism (including actuators outside the optical path). In this paper, we present another type of lens using an electroactive polymer. The purpose of this paper is to describe self-deformable thin lens without any external mechanism. We fabricated an IPMC lens with blur-sharp effect. The IPMC lens is composed of both a thermally imprinted, transparent, and concave-structured Nafion membrane and partially electroless-plated the platinum electrode. By applying a low AC voltage to the IPMC lens, the IPMC deforms upward and downward for itself. As a result, the blur-sharp effect was obtained in the concave-structured Nafion membrane. The proposed method for fabricating blur-sharp effect lens has a large potential to realized very small electro-optics, especially in the field of consumer electronic devices.

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KEYWORDS: Ionic polymer-metal composite, Thermal imprint lithography, Nafion, Blur-sharp effect, IPMC

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1. Introduction

Adaptively compact focus lenses have been attracted for visible applications including endoscopes, cell phone cameras, and machine vision apparatus. Unlike a bulky, complicated, and expensive electrical motor assemblies found in traditional focus tunable lenses, the adaptive lenses can be easily obtained by varying either the refractive index of the optical medium or the lens curvature[1-4]. But, refractive index variation is typically limited to specific liquid crystal materials which have inherent optical limitations, such as polarization effects and relatively slow response times[5,6]. A lens curvature variation is generally generated by deforming flexible membranes containing a liquid, where the lens shape is altered in internal volume change through liquid mass transfer or lens periphery actuation to induce deformation in the optical path. Various actuation mechanisms are used to drive the deformation of these tunable lenses including electric motors, rotating screws, piezoelectric elements, or dielectric elastomer actuators (DEAs)[7,8]. In particular, among these tunable lenses, transparent DEAs are promising recently as a self-contained tunable lens with an integrated electrical actuator in the optical path of the lens. However, the lens configurations of DEAs locate the actuator outside the optical path. Besides, the actuation of the DEAs is operated at relatively high voltage[9,10]. Therefore, a low-voltage driven, compact, and self-contained adaptive lens is strongly required.

Ionic polymer-metal composites (IPMCs) as one

of the ionic electroactive polymers (EAPs) exhibit a large bending displacement in the presence of a low applied voltage. An IPMC consists of an ion exchange membrane sandwiched between two noble metal plates. When a small potential is applied to an IPMC in the hydrated state, the transport of hydrated cations within an IPMC membrane leads to mechanical deformation. IPMC undergoes bending deformation toward the anode as a result of volume expansion on the cathode side. IPMCs have no moving parts and require only a small operating voltage for their actuation, and consequently they have many advantages over conventional mechanical actuators. Herein, we report a low-voltage driven, compact, tunable, and self-contained adaptive lens employing the IPMC actuator. A detailed description of the design, fabrication, and actuation of the lens is discussed by applied low voltage. Also, an analysis of the membrane deformation and optical properties of the lens is examined in depth.

2. Fabrication of the Adaptive Lens

2.1 Sample preparation

A Nafion® membrane 0.18 mm thick (N117, Dupont Inc., U.S.A) was used as the ionic polymer membrane. To implement the concave structure onto the Nafion membrane, we introduce the thermal imprint lithography (TIL). Before introducing platinum electrodes, we attach the sticky tapes to obtain transparent Nafion membrane, where we intentionally prevent the chemical reduction both side of Nafion membrane,

consequently resulting in showing the opposite side through the translucent Nafion membrane. Platinum electrodes were created on both surfaces of membranes by chemical reduction process described in the literature[11-13]. The membrane was cleaned with hydrochloric acid and deionized water, and immersed in the aqueous solution of tetraammineplatinum chloride ($[\text{Pt}(\text{NH}_3)_4]\text{Cl}_2$) to exchange protons for platinum ions. The film was rinsed with deionized water, placed in 500 mL of stirring water at 40 °C, and 5 mL of 5 wt. % aqueous sodium borohydride solution (NaBH_4) was added every 30 min as increasing the temperature gradually up to 60 °C for 12 h. To improve the performance of the IPMC lens actuator, the number of platinum electroless plating cycles was repeated fourth for making the enough electrode layer. Platinum electrodes were created on both surfaces of stacked IPMC by a chemical reduction process. IPMC actuators 15mm wide and 40 mm long were fabricated. Also, IPMC lens with flat-surfaced Nafion membrane is prepared with above mentioned method except for additional TIL. Before the experiments, IPMC was immersed in a 0.1M lithium chloride solution (LiCl , Adrich) for a couple of days to exchange cations. Changes in the chemical properties and transparency of the thermally-imprinted membrane were analyzed using FT-IR (Fourier transform infrared, Nicolet, Thermo) in ATR (Attenuated Total Reflection) mode and UV/Vis spectra (Ultraviolet-visible spectra, Jasco, V-570).

2.2 Fabrication

The schematic illustration for the preparation of adaptive IPMC lens is shown in <Figure 1>. It is composed of both a thermally imprinted, transparent, and concave-structured Nafion membrane and partially electroless-plated the platinum electrode. The whole procedure for the preparation of IPMC lenses with concave-patterned Nafion membranes and untreated Nafion membrane is shown schematically, as seen in <Figure 1>. For fabricating the concave-patterned Nafion membrane, firstly, as shown in <Figure 1 (a)>, we used the TIL method. It is well-known, easy and feasible method to transfer master molds to other polymer substrates. Convex pattern with diameter/height was 5/5 mm, were designed. The patterned master molds with appropriated dimensions were prepared by Lathe machining. A 180 um-thick Nafion 117 (DuPont) film was placed between the master molds, and pressed with 1 MPa at 120 °C for 1 h in a vacuum oven[11,12]. Followed by slow cooling to room temperature and release of the pressure, the membrane was immersed in distilled water at 50 °C for 24 h so that it was spontaneously detached from the master molds.

Both sides of detached Nafion 117 were attached by the sticky tape to observe the opposed site through the transparent Nafion membrane. Platinum electrodes were created on both surfaces of membranes by chemical reduction process described in the literature [13-15]. The membrane was cleaned with hydrochloric acid (HCl) and deionized water, and immersed in the aqueous solution of

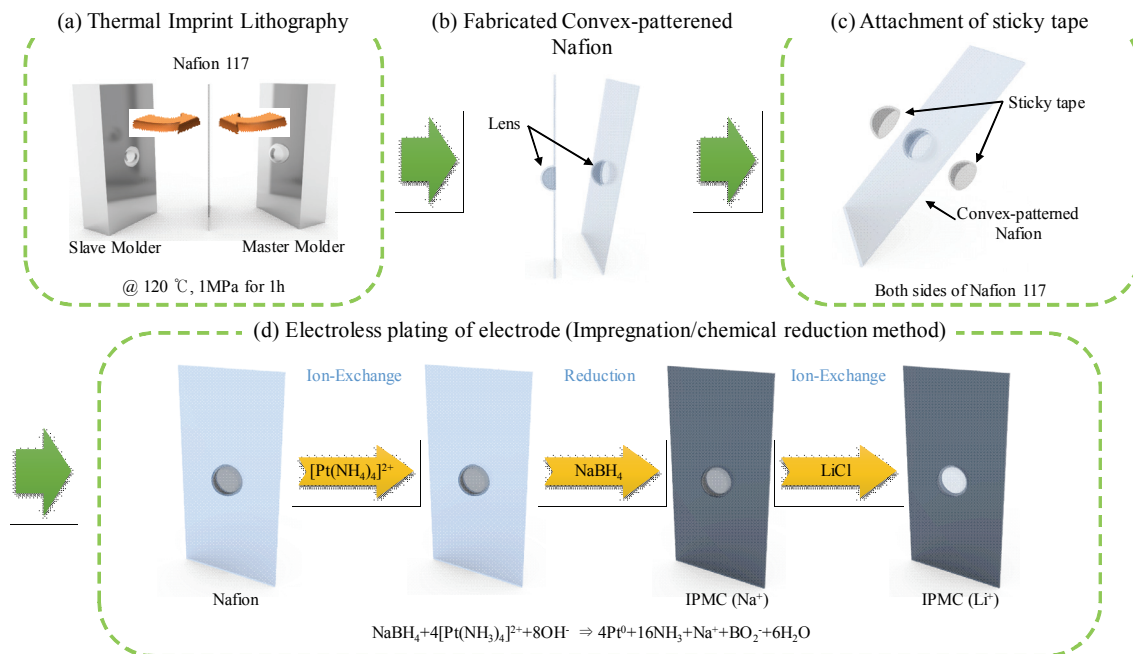


그림 1. 적응형 IPMC 렌즈의 제작공정

Figure 1. The schematic illustration for the preparation of adaptive IPMC lens.

tetraammineplatinum chloride ($[\text{Pt}(\text{NH}_3)_4]\text{Cl}_2$) to exchange protons for platinum ions. The film was rinsed in 500 mL deionized water, which is stirring at 40 °C, and 5 mL sodium borohydride (NaBH_4 , 5 wt. % aqueous) solution was added every 30 min as increasing the temperature gradually up to 60 °C for 12 h. To improve the performance of the IPMC lens actuator, the number of platinum electroless plating cycles was repeated fourth for making the enough electrode layer. Platinum electrodes were created on both surfaces of stacked IPMC by a chemical reduction process. After IPMC preparation, the surface resistance is about 4 ohm/cm which means that electroless plating onto the Nafion membrane is successfully fabricated for the IPMC lens. Finally, the sticky tape onto Nafion

membrane is removed, of which the chemical reduction of platinum electrode does not occur, thus we can observe the opposite sites through the transparent Nafion membrane. IPMC actuators 15mm wide and 40 mm long were fabricated. Also, an IPMC lens with Nafion membrane is prepared with above mentioned method except for additional TIL.

3. Experiment and Results

In order to investigate changes in the chemical properties and transmittance of the thermally imprinted membrane, UV spectra and FT-IR ATR spectra were obtained from 64 scans at a resolution of 4 cm^{-1} from 4000 to 400 cm^{-1} , as seen in <Figure 2> and <Figure 3>, respectively.

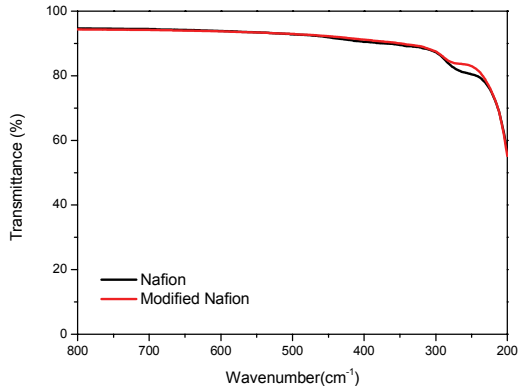


그림 2. IPMC와 TIL공법을 적용한 IPMC의 UV/Vis spectra 결과
Figure 2. UV/Vis spectra of the pristine Nafion and thermally imprinted Nafion after IPMC preparation

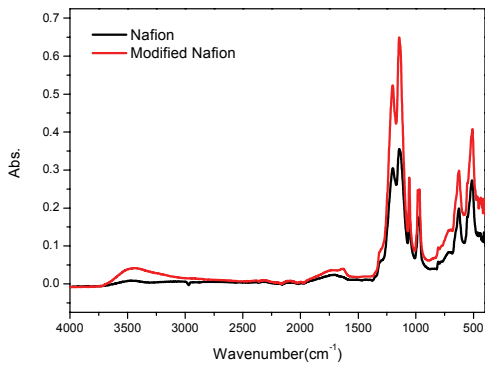


그림 3. IPMC와 TIL공법을 적용한 IPMC의 FT-IR spectra 결과
Figure 3. FT-IR spectra of the pristine Nafion and thermally imprinted Nafion after IPMC preparation.

<Figure 2> and <Figure 3> present the UV/Vis spectra and FT-IR Spectra of the pristine Nafion and thermally imprinted Nafion after IPMC preparation. The main absorption bands, vibrational bands, and transmittance of Nafion membrane have already been published in prior research. No peak shift was observed in the FT-IR and UV spectrum of thermally-imprinted Nafion 117 membrane at 120 °C for 1 h under 1

MPa, which was measured by considering all wave numbers similar to that of untreated Nafion 117 membrane. This result indicates that thermal imprinting for preparing the concave structure did not cause any major changes in the chemical properties of Nafion membrane and thus resulted in maintaining the transparency.

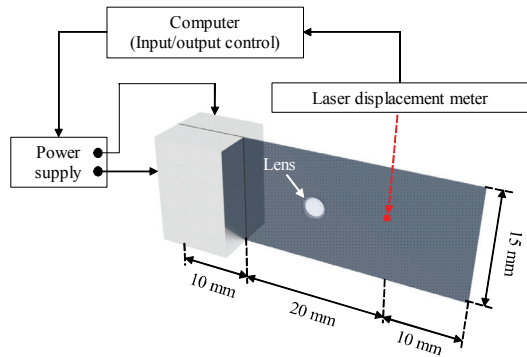


그림 4. 제안하는 렌즈의 변위를 측정하기 위한 실험 환경
Figure 4. Experimental setup for measuring the displacement of the prepared lens.

<Figure 4> shows the experimental setup for investigating the displacement of the developed IPMC lens. The displacement was measured at a point 20 mm away from the grip because the large bending motion of the IPMC beam yields deflections exceeding the limitation of the laser displacement measurement system. The displacements of the IPMC lens were measured under five different AC voltages (1, 3, 5, 7, 10 V) with a 0.1 Hz square wave in the atmosphere. The displacements of IPMC lens follow the oscillations of the input voltage well. The deflection of the beam was measured using a laser displacement measuring system (CP08MHT

80, Wenglor Sensors, Ltd, U.S.A.), and the bending profile was recorded by a camera (HMX-GF20BD, Samsung, Korea). All the measurements were recorded until they reached a steady-state, and repeated at least 10 times for each measurement.

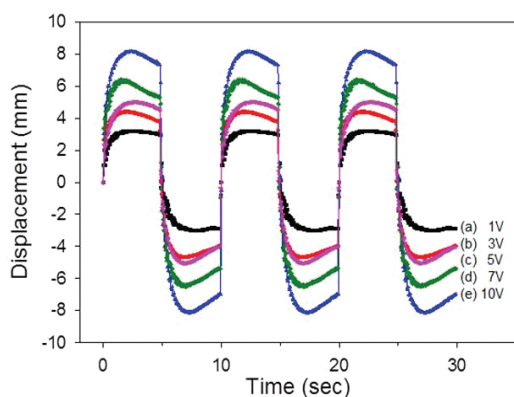


그림 5. 전압 인가에 따른 적응형 IPMC 렌즈의 변위

Figure 5. The displacement behavior of the developed lens with various AC applied voltage under 0.1 Hz square wave

<Figure 5> shows the displacements of the IPMC beams under a 1, 3, 5, 7, 10 V with 0.1 Hz square wave. It is expected that high applied voltage results in large displacement. As the applied voltage increased, the IPMC lens displacements clearly increased. The maximum value of the displacement of the IPMC lens was saturated about 1.5 sec under a 1 V, 0.1 Hz square wave. But, the maximum value of the displacement of the IPMC lens was obtained at about 2 sec under 3~10 V, 0.1 Hz square wave. After that, the displacement of the IPMC lens slowly decayed with time. Although the displacement of the IPMC lens with increasing applied voltage is gradually larger, the decay

phenomena did not disappear. The decay of the displacement of the pupil is thought to come from the decrease in the generation force of IPMC, due to evaporation of water in IPMC or the back relaxation of IPMC[16].

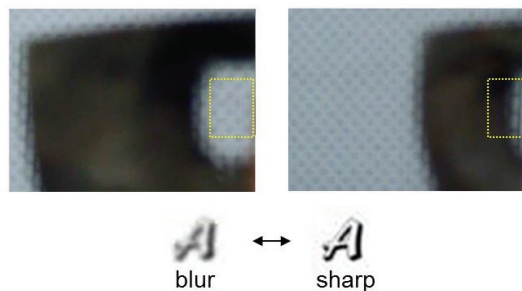


그림 6. 직류 전압 20 V, 0.1 Hz 사각파가 인가된 적응형 IPMC 렌즈에서 추출된 이미지 결과

Figure 6. Images collected using the IPMC lens under DC 20 V, 0.1 Hz square wave

The operation of untreated IPMC lens using pristine Nafion membrane lens was collected under AC 2 V, 0.1 Hz square wave to observe the blur and sharp effect through the Nafion membrane where the chemical plating does not happen. <Figure 6> shows a photograph of IPMC actuator lens investigated in this study, and which was used to demonstrate its blur effect. The blur phenomenon of this IPMC actuator lens was observed when a AC voltage of 2 V was applied, resulting in the image becoming altered. Resultingly, initially in blurred, when a DC voltage of 20 V was applied to a variable IPMC actuator lens, the image produced by it became sharp. These results demonstrated that blur-sharp effect of the IPMC actuator lens could be adjusted by varying the voltage applied for itself.

4. Conclusions

A transparent IPMC lens, where chemical reduction of platinum was not happening, was sequentially fabricated using a thermal imprint technique, a bonding process of sticky tape, and a chemical reduction method of platinum electrode. After thermally imprinting Nafion film, the chemical composition and the transmittance of was not altered as investigated using FT-IR and UV-VIS spectroscopy. When a voltage is applied to the fabricated IPMC lens module, blur-sharp effect is observed. The displacement of IPMC lens is larger by increasing the voltage applied. This system is proposed to solve the power consumption problem of widely used coil motors, and also could anticipate applications in various portable optic devices, such as digital cameras, camcorder, and cell phones.

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이온 중합체 금속 혼합물을 이용한 적응형 렌즈 개발

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요 약

입의 거리에 떨어진 물체를 자세히 보기 위하여 다양한 가변 초점 렌즈들이 사용되고 있다. 이러한 가변 초점 렌즈들은 두 개 혹은 그 이상의 렌즈들의 거리를 변경하거나, 전기습윤 메커니즘, 액정 물질, 혹은 펌프를 이용한 유체를 이용하여 초점을 조절하였다. 이러한 렌즈들은 균일하지 않은 전기장에 의해 수차가 발생하거나, 유체가 증발한다는 단점을 가지고 있다. 이러한 렌즈들의 또 다른 문제점으로는 구동을 위해 렌즈의 근처에 액추에이터가 있어야 하거나, 유체를 넣거나 빼기 위한 펌프 등 외장 장치들이 필요하다. 본 연구에서는 전기활성 고분자를 이용한 새로운 타입의 렌즈를 제안한다. 제안하는 렌즈는 자가변형이 가능하며, 매우 얇고 가볍다는 장점이 있으며, 외부의 장치 없이 구동이 가능하다. 개발된 렌즈는 흐림/선명함 효과를 낼 수 있는 이온 중합체 금속 혼합물(IPMC)이다. 개발된 IPMC 렌즈는 열 각인 방법을 이용한 투명하고 오목한 형상의 나피온 필름과 비전착성 백금 전극으로 이루어져 있다. 낮은 AC 전압이 IPMC 렌즈에 인가되면, IPMC는 위와 아래 방향으로 변형된다. 결과적으로, 오목한 형상의 나피온 필름을 이용하면 흐림/선명 효과를 얻을 수 있다. 흐림/선명 효과 생성이 가능한 렌즈를 만드는 제안된 방법은 아주 작은 전기 광학 분야에서 큰 잠재력을 가지고 있으며, 특히 소비자 전자장치에서 사용될 수 있을 것으로 보인다.

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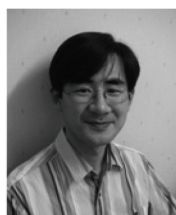
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