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Ionic-Type Actuator Based on Polypyrrole and Solid Polmer Electrolyte Working in Air

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The oxidation and reduction of conducting polymers(CPs) can be accompanied by significant changes in the volume of the polymer. The switching of a CP between the oxidized and the reduced states is a reversible process that can be driven electrochemically by small changes in cell voltage. This way of controlling the volume of a CP has been investigated as the basis of a new generation of actuators.[1,2] Polypyrrole(PPy) is one of the most widely investigated CPs for actuator due to its facile preparation, stable redox reaction over a wide pH range and operation in biological media.

Liquid electrolyte is essential for actuation of conducting polymer actuators. However, it may be an obstacle to the practical use of PPy actuator that usually requires electrolyte solution for actuation. Our research theme is focussed on this problem. We have investigated solid polymer electrolytes for the substitution of electrolyte solution which means the possibility of extended various applications of CP actuators.[3] In this work, the candidate materials of solid polymer electrolyte for this aim are investigated and a new solid state CP actuator, fully polymeric, based on two PPy film electrodes and a solid polymer electrolyte(SPE), polyurethane/$Mg(ClO_4)_2$ was accomplished.

PPy was grown electrochemically on stainless steel electrode with sodium perchlorate($NaClO_4$) as a dopant. PPy was characterized by using 4-point probe technique, scanning electron microscopy(SEM) and infrared spectroscopy. Polyurethanes(PUs) were synthesized using a two-step method based on polydimethylsiloxane(PDMS) with different molecular weights 1000, 1800, and 3200. The properties of SPE were measured by using fourier transform-infrared spectroscopy(FT-IR), alternative current(AC) impedance measurements, and differential scanning calorimetry(DSC). Fig. 1 shows the fabrication process of tri-layer actuator. We fabricated the tri-layered CP actuator composed with one SPE layer between two PPy layers and measured the displacement.

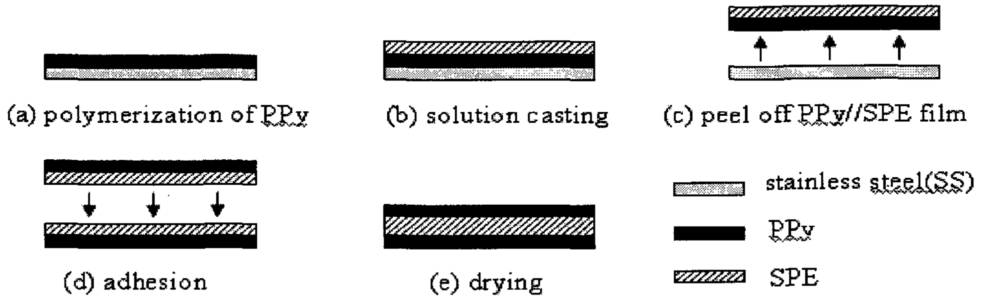
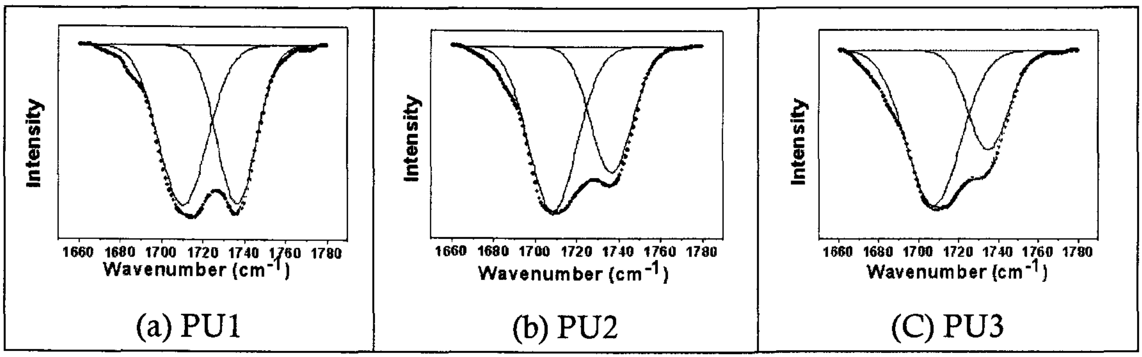


Figure 1. Fabrication process of tri-layer actuator.

Fig. 2 shows IR spectra of the carbonyl stretching region in PUs. Samples were represented by PU1, PU2, and PU3 according to the Mw of PDMS, 1000, 1800, and 3200, respectively. The band at 1730cm^{-1} is assigned to the stretching of free urethane carbonyl groups, and the peak at 1708cm^{-1} corresponds to the stretching of the hydrogen bonded urethane carbonyl groups.[4] The fraction of hydrogen bonded urethane carbonyl groups obviously increased with the increase in the Mw of PDMS. From this result, it could be known that the degree of phase separation between hard and soft segments increased, because the hydrogen bonding of urethane carbonyl groups enhanced the aggregation of hard segments.



(a) PU1 (b) PU2 (C) PU3

Figure 2. The carbonyl stretching of Polyurethanes.

The soft segment Tg of PUs decreased with the increase in the Mw of PDMS. This result is attributed to the fact that the degree of phase separation increased with Mw of PDMS. Also, the Tg of PDMS soft segment for the PU based SPEs increased with increasing the salt concentration.This arises from that the coordination of Mg^{2+} ions with the PDMS soft segment not only arrests the local motion of the polymer segments but also forms physical cross-linking.

And the result of IR spectroscopy proved that the perchlorate (ClO_4^-) ion was incorporated into the PPy structure. The SEM observation of the cross section of the actuator with a tri-layer structure demonstrated that the SPE layer adhered well to the PPy film. Tri-layer devices have been constructed 20mm long, 3mm wide, and 170-220㎛ thickness. The PPy film on the one side of the tri-layer acts as working electrode while the other one on the other side acts as a counter electrode.

An anodic potential applied to the PPy film connected as working electrode produced a bending movement of the free end in the direction of the counter electrode. And a movement in the opposite direction was observed when a cathodic potential was applied. So the tri-layer actuator was bent in the direction of the working electrode.

To find the proper thickness of PPy film, we measured the displacement of actuators according to the thickness of PPy film. The displacement showed maximum value at 8-10㎛ thickness. And displacements of all samples decreased with increasing the salt concentration in SPE. All the results obtained in this work show the feasibility of electrochemomechanical devices based on PPy and SPE film able to work in air.

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