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Spring type conducting polymer actuator working in air

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ABSTRACT

Although major advances in actuator performances have been obtained in the last few years, the actuation of conducting polymer (CP) actuator is still limited to bending movement in liquid electrolyte. It restricts the various application fields of CP actuator. So in this study, spring type CP actuator which can produce linear movement and work in air is prepared. It is composed of two polypyrrole (PPy) films having different actuation mechanism and polyurethane (PU) based solid polymer electrolyte (SPE). Even though the ionic conductivity of PU based SPE is low, the actuation behavior of CP actuator especially working in air is much influenced by the flexibility rather than the ionic conductivity of SPE. Then PU based SPE with high flexibility is used in a spring type CP actuator. The morphology of PPy films, ion conductivity of SPE, actuation movements according to its length and applied voltage and loading ability of actuator were investigated. SPE had a maximum conductivity of 2.20×10^{-6} S/cm at room temperature for 15 wt% of $Mg(ClO_4)_2$ salts and the actuator which was fabricated in 21 mm length showed maximum displacement at 12 V. Also it was confirmed that spring type CP actuator could Exhibit 10 MPa of loading ability through the tensile strength test. As a result, solid-state spring type CP actuator having both linear movement and loading ability was demonstrated.

1. Introduction

In the last few decades, several soft actuators with volume changes of intrinsically conducting polymers (CPs) during redox process have been studied extensively. This volume change can be expressed as electrochemomechanical deformation (ECMD) [1].

CPs are organic semiconductor characterized by alternating single bond and double bonds along the polymer backbone (conjugation), a structure that results in a delocalized positive charge if an electron is removed from the polymer. To maintain charge neutrality, negatively charged anions are incorporated into the polymer to compensate these positive charges on the polymer backbone. The electrons can be reversibly returned by applying a more negative potential to reduce the polymer and leave the backbone neutral, or uncharged. A number of things change when oxidation level of the polymer is altered. Most of all, the primary mechanism for volume change is mass transport. When ions and/or solvent enter the polymer, it expands, and when they exit, it contracts. It can be used as actuator showing bending displacement [2]. Their attractive features as actuators are large strain, light weight, and low voltages for actuation.

Amongst CPs, polypyrrole (PPy) is widely investigated because it is electrochemically active over a wide range of pH, easy to prepare and has good environmental stability under ambient condition [3]. In the development of CP actuators, most effort has concentrated on improving the strain and response time of actuator. However although major advances in actuator performances have been obtained in the last few years, the actuation of CP actuator is still limited to bending movement. It restricts the application of CP actuator in semiconductor devices, position control devices, and medical instruments.

Also CP actuator has to need liquid electrolyte for their actuation. However the operation of CP actuator in air is possible only if liquid electrolyte can be substituted by solid polymer electrolyte (SPE), which means the possibility of extended various applications of CP actuators. SPEs of CP actuator require flexibility and mechanical properties. In particular, polyurethane (PU) represents the high flexibility due to their phase separation and the excellent mechanical properties [4].

So in this study, spring type CP actuator which can produce linear movement using two PPy films having different actuation mechanism and PU based SPE were prepared.

2. Experimental

2.1. Polymerization of polypyrrole (PPy)

Pyrrole (Py, Mw = 67.09, Acros Organics) was distilled and stored at −16 °C before use. Dodecylbenzenesulfonic acid sodium salt (NaDBS, Mw = 348.48, Junsei Chemical Co., Ltd.) and sodium

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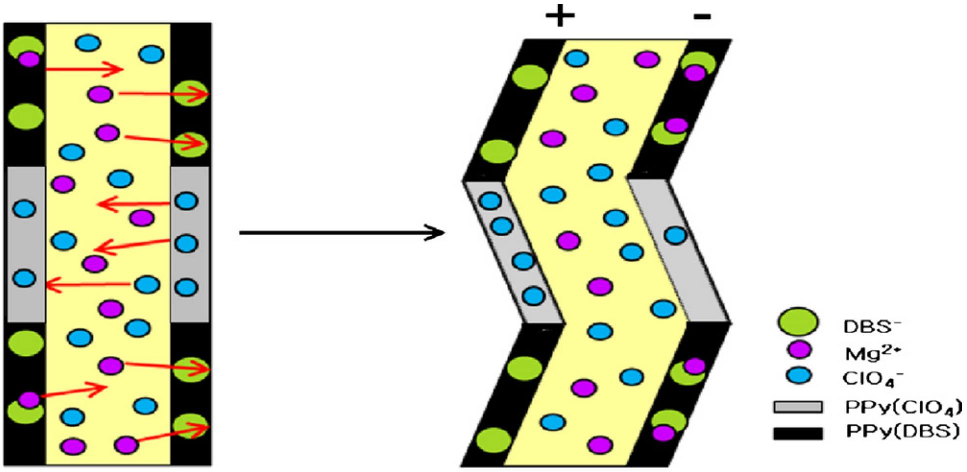

Fig. 1. Mechanism of spring type CP actuator.

perchlorate ($NaClO_4$, Mw = 140.46, Junsei Chemical Co., Ltd.) were used without further purification. Distilled water and acetonitrile (Mw = 41.05, 99.5%, Junsei Chemical Co., Ltd.) were used as solvent for the electrochemical synthesis of PPy.

PPy films were electrochemically polymerized from aqueous dispersions of 0.15 M pyrrole monomer containing 0.05 M dodecylbenzenesulfonic acid sodium salt (NaDBS) or from non-aqueous dispersions of 0.15 M pyrrole monomer containing 0.15 M sodium perchlorate ($NaClO_4$). At this time polymerization time of PPy(DBS) and PPy(ClO_4) was 20 and 10 min, respectively. A stainless steel electrode, having a surface area of 3×3 cm^2, was used as a working electrode and a Pt mesh sheet was used as a counter electrode. An Ag/AgCl electrode was used as a reference electrode. All electrochemical polymerizations were performed at a constant potential of 2 V at room temperature. After growth, PPy films were rinsed thoroughly with solvent and dried at room temperature for 24 h.

2.2. Preparation of solid polymer electrolyte (SPE)

Poly(tetramethylene adipate glycol) (PTAd, Mw = 2000, Union-chemicals Inc.) was degassed at 60 °C under vacuum for 24 h before use. 4,4′-Methylenebis(phenylene isocyanate) (MDI, Mw = 250.26, Aldrich Co., Ltd.) and 1,4-butanediol (1,4-BD, Mw = 90.12, Junsei Chemical Co., Ltd.) were distilled under vacuum. N,N-dimethylacetamide (DMAc, Mw = 87.12, Junsei Chemical Co., Ltd.) as solvent was used without further purification. Also, magnesium percholrate ($Mg(ClO_4)_2$, Mw = 223.21, Aldrich Co., Ltd.) was dried in vacuum at 90 °C overnight and stored in a desiccator under nitrogen.

PU was synthesized by a two-step polymerization procedure. PTAd was reacted with MDI and the mixture was stirred at 60 °C for 2 h with catalyst. After that, 1,4-BD was added to the prepolymer at 60 °C for 3 h. The hard segment content of synthesized PU was fixed at 25 wt% [5]. The total process was done under nitrogen atmosphere. The synthesized PU was precipitated into methanol solution in order to eliminate the unreacted monomers and oligomers. PU based SPEs were prepared by solution casting method with various $Mg(ClO_4)_2$ concentrations. The thickness of SPE films was controlled between 150 and 200 μm.

2.3. Fabrication of spring type PPy film

The direction of bending displacement in actuator with PPy(ClO_4) or PPy(DBS) is opposite when the same voltage (oxidation or reduction) is applied. So if we introduce two films in one electrode, it could produce two directional bending displacements. Therefore, spring type PPy film having both cation-driven ECMD (PPy(DBS)) and anion-driven ECMD (PPy(ClO_4)) was fabricated to produce two directional bending displacement for linear movement of actuator. In other words, spring type PPy film should be composed of two PPy

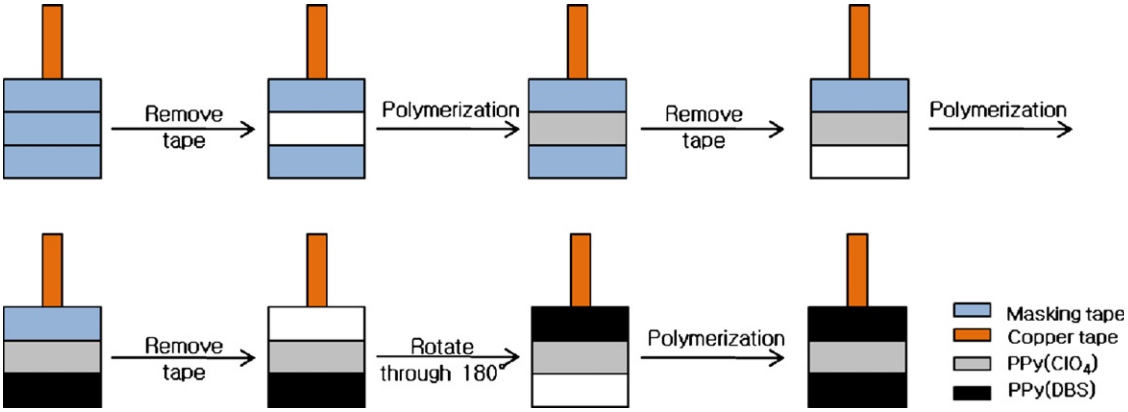

Fig. 2. Preparation process of spring type PPy film.