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A polypyrrole rotor driven by sorption of water vapour

Hidenori Okuzaki, Takayoshi Kuwabara and Toshio Kunugi*
Department of Applied Chemistry and Biotechnology, Faculty of Engineering, Yamanashi University, 4-3-11 Takeda, Kofu 400 Japan
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The polypyrrole films containing perchlorate were electrochemically synthesized and the bending and recovery motion of the film obtained have been investigated. The principle of motion was based on a reversible sorption of water vapour on one side of the film, causing an expansion of the film surface. On the basis of this phenomenon, we have devised a polypyrrole rotor driven by sorption of water vapour, producing a continuous rotation at a speed of 21 cm min^{-1}. © 1997 Elsevier Science Ltd.

(Keywords: polypyrrole film; sorption of water vapour; rotation)

Introduction

The system transducing the chemical free energy change directly into a mechanical work[1,2] using polymeric materials is of importance from a technological viewpoint. A number of studies in this area have been focused on swollen polymeric gels because a gel changes its size or shape in response to various stimuli such as temperature[3], pH[4] or an electric field[5-7].

Previously, we have reported that the electrochemically synthesized polypyrrole solid films undergo intensive bending in ambient air without employing the stimuli of heat, ions or an electric field[8]. The principle of motion is based on a reversible van der Waals sorption of water or polar organic molecules onto the film[9], which distinguishes it from electrochemical doping[7]. Further, we have made a new class of polymeric rotor which uses the polypyrrole belt as a working substance and uses water and iodomethane as sorbates.

Here we demonstrate a novel polypyrrole rotor driven by using only water capable of transducing the chemical free energy change of sorption directly into a continuous rotation. It is found that the polypyrrole belt rotates at a speed of 21 cm min^{-1}.

Experimental

Materials. Pyrrole (Wako Chem. Co., Ltd.), used as a monomer, was purified by distillation before use. Tetraethylammonium perchlorate used as an electrolyte and propylene carbonate (Kanto Chem. Co., Ltd.) were commercially available and used without further purification.

Preparation of polypyrrole film. Polypyrrole films containing perchlorate (PPy/ClO_4) were electrochemically synthesized by anodic oxidation of pyrrole[10]. The polymerization was carried out for 12 h at −20°C. After polymerization, the polypyrrole film was peeled from the electrode and soaked in a large amount of propylene carbonate and then dried overnight in a vacuum. The thickness of the film obtained was 21 μm and elementary analysis gave a composition of $C_{4.18}H_{4.02}N_{0.84}(ClO_4)_{0.34}$. Young's modulus and tensile strength of the film were 610 MPa and 34 MPa, respectively.

Measurements. The apparatus for the measurement of bending of the polypyrrole film is schematically shown in *Figure 1*. The polypyrrole film was 25 mm long, 5 mm wide, 21 μm thick, and was suspended from a chuck made of stainless steel. An electric shutter was equipped with a glass tube (50 mm long and 6 mm in diameter) stuffed with a tissue containing pure water, and the tube was located at a distance of 2 mm from one side of the film. The extent of bending was evaluated by measuring a geometrical change of the film at its free end using a video camera. The relative humidity was measured using a hygrometer (MC-P, Panametrics Japan Co., Ltd.) which was located at a distance of 2 mm from the shutter. All measurements were carried out under thermostatic conditions (temp. 25°C).

Results and discussion

Figure 2 shows time profile of bending of the polypyrrole film. When the shutter opens, the film rapidly bends to the opposite direction. The displacement attains a maximum value of 11.7 mm within 2 s, followed by a decrease and then holds at 9.5 mm corresponding to the bending angle of about 30°. The relative humidity near the shutter increases from 50% to 68%. The principle of motion is ascribed to a reversible sorption of water vapour onto the film causing an expansion of the film surface[9]: the film contains 4.4% of water in ambient air and when the shutter opens, further sorption of water occurs and the content attains 7% within 5 s. The expansion of the film might be interpreted as a conformational change of the polypyrrole chains due to sorption of water vapour via weak interactions. The bending is caused by the difference between the expansion on both sides of the film due to anisotropic water sorption. The maximum expansion of the film surface calculated from the bending curve is about 0.3%. The slight decrease of the displacement which corresponds to a bending backward, may correlate with a penetration of water molecules into a polypyrrole network. If the shutter closes, the sorbed water desorbs

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* To whom correspondence should be addressed

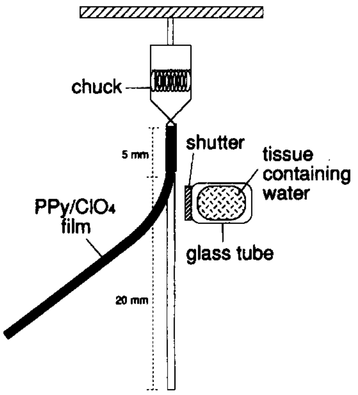

Figure 1 Apparatus for the measurement of bending of the polypyrrole film

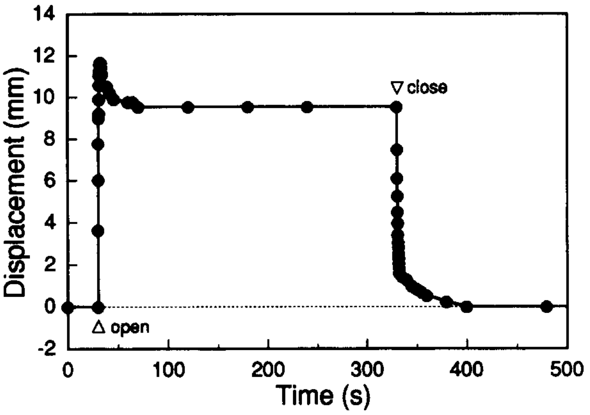

Figure 2 Time profile of bending of the polypyrrole film. The thickness of polypyrrole film: 21 μm. Temp. 25°C, 50% RH

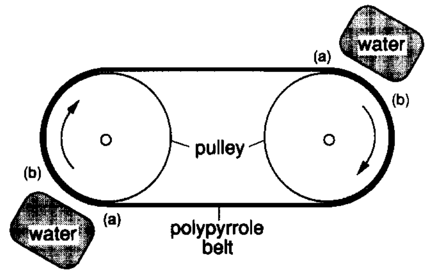

Figure 3 Schematic construction of the polypyrrole rotor (side view). Diameter of pulleys: 10 mm; wheel base: 20 mm

from the film surface and scatters into ambient air[9], so that the film recovers to its original shape. The initial speeds of bending and recovery motion are 12.9 mm s^{-1} and 10.3 mm s^{-1}, respectively.

The films made of hygroscopic polymers such as poly(acrylic acid) or a kind of cellulose exhibited only weak and slow bending. On the other hand, those made of polyolefins, polyamides, polyesters, polystyrenes and polycarbonates did not bend. Thus, quick bending and recovery motion is peculiar to the polypyrrole and the detailed mechanism is now studied.

On the basis of this phenomenon, we have devised a novel polypyrrole rotor driven by sorption of water vapour. The schematic construction of the rotor is shown in *Figure 3*. A polypyrrole belt was prepared by connecting two films (25 mm long, 5 mm wide and 21 μm thick) and was wound around two pulleys. When tissues containing pure water are brought to a corner of each pulley diagonally the curvatures of the belt increase near the tissues due to anisotropic sorption of water vapour. The mechanical stress generated by the bending makes the belt move from the straight position (a) to the curved one (b). Thus, a net rotational force acts on the pulleys and causes a clockwise rotation. The rotation brings a new surface of the belt to the tissues, thereby enabling continuous rotation. Here, the sorbed water may desorb and scatter into ambient air until the belt rotates a half-cycle where the following sorption occurs. The speed of rotation is 21 cm min^{-1} corresponding to the rotation of pulleys at 6–7 r.p.m., which is nearly the same with that of the rotor using both water and iodomethane[8].

The polypyrrole rotor works without consuming any material but using only water. This system has the following advantages: (1) the construction is quite simple; (2) it operates in ambient air without producing heat or by-product; (3) it provides a combination of sensor and actuator; and (4) a high reproducibility of motion is obtained because of no incidental chemical reactions.

Conclusions

The electrochemically synthesized polypyrrole solid film exhibits quick bending and recovery motion in ambient air. The principle of motion is based on a reversible sorption of water vapour onto the film. The displacement of the film attains 11.7 mm within 2 s and then holds at 9.5 mm. The initial speeds of bending and recovery motion are 12.9 mm s^{-1} and 10.3 mm s^{-1}, respectively. By using this phenomenon, the polypyrrole rotor has been devised which uses the polypyrrole belt as a working substance and water as a sorbate, producing a continuous rotation at a speed of 21 cm min^{-1}.

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