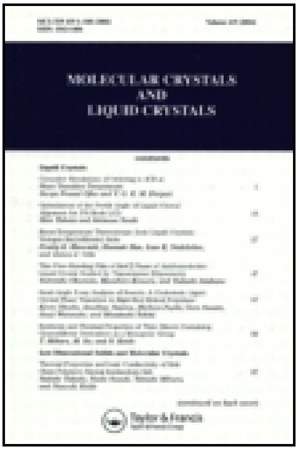

Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Size Effect of Anisotropic Polypyrrole Actuator

Kazuya Tada [a], Hirokazu Shonaka [a] & Mitsuyoshi Onoda [a]

[a] Division of Electrical Engineering, University of Hyogo, Himeji, Hyogo, Japan

Version of record first published: 31 Jan 2007

To cite this article: Kazuya Tada, Hirokazu Shonaka & Mitsuyoshi Onoda (2005): Size Effect of Anisotropic Polypyrrole Actuator, Molecular Crystals and Liquid Crystals, 443:1, 137-141

To link to this article: http://dx.doi.org/10.1080/15421400500247086

Mol. Cryst. Liq. Cryst., Vol. 443, pp. 137–141, 2005

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400500247086

Size Effect of Anisotropic Polypyrrole Actuator

Kazuya Tada
Hirokazu Shonaka
Mitsuyoshi Onoda
Division of Electrical Engineering, University of Hyogo, Himeji, Hyogo, Japan

The size effect, the length dependence of actuation behavior, of anisotropic polypyrrole (PPy) film obtained by electrochemical polymerization in a thin slab vessel consisting of PTFE walls has been studied. It was found that the active area of the actuator is limited within 3 mm from the electrolyte surface when it is simply soaked in the electrolyte. The active area is doubled by electrically insulating the actuator from the electrolyte surface. These results suggest that the active area of the PPy actuator is mainly limited by two factors, the enhancement of electrochemical reaction rate at the electrolyte surface and the reduction of electrical conductivity of the actuator upon undoping.

Keywords: artificial muscles; conjugated polymers; electrochemical actuator; polypyrrole, self-organization

1. INTRODUCTION

When a conducting polymer such as polypyrrole (PPy) is electrochemically doped and undoped, it changes not only the electrical conductivity but the volume [1,2]. Since the volume change is governed by electrochemical reaction, the driving voltage of actuators based on this mechanism is very low in comparison with other actuators which are driven by the electrostatic force. This unique feature of electrochemical actuator using conducting polymer induced a number of studies.

A PPy pipe can be electrochemically grown in a thin pipe of poly (tetrafluoro-ethylene) (PTFE) with inner diameter of 1 mm. The PPy pipe through this process was found to consist of an anisotropic PPy

Address correspondence to Kazuya Tada, Division of Electrical Engineering, University of Hyogo, 2167 Shosha, Himeji 671-2201, Hyogo, Japan. E-mail: tada@eng.u-hyogo.ac.jp

film, i.e., the outer and inner walls have quite different morphology and the former shows smooth and glossy texture while the latter was non-glossy [3,4]. A bending-beam type actuator based on conjugated polymer is usually fabricated as a bimorph, that is, an electrochemically active conjugated polymer is laminated with an inert polymer film such as a Scotch tape. However, a piece of the anisotropic PPy film is readily available as an actuator because of anisotropic volume change at a certain doping level. In other words, a self-organized bending-beam actuator of PPy can be grown in a PTFE pipe.

The anisotropy of the PPy film along thickness apparently originates from the difference in environments during polymerization. That is, the outer wall contacts with PTFE wall while the inner one is surrounded by the polymerization electrolyte. By replacing the PTFE pipe with a thin slab vessel consisting of PTFE walls, a large size of anisotropic PPy film can be obtained [5,6]. Here, we report on the size effect, i.e., the length dependence of the reduction current, of the actuator.

2. EXPERIMENTAL

A rectangular strip (15 mm $\times$ 1 mm) was cut from an anisotropic PPy film electrochemically prepared in a PTFE slab vessel to be examined as an actuator. The fabrication of the anisotropic PPy film and some properties as an actuator can be found in our previous publications [5,6].

The PPy strip was dipped into aqueous solution containing 1.0 mol/l of *p*-toluenesulfonic acid sodium salt (PTSNa), and it was driven as an actuator by supplying stepwise potential change from 0.2 V vs. Ag/Ag^{+} (doped state) to -0.85 V vs. Ag/Ag^{+}(undoped state) by a potentiostat. In this study, the length was changed by trimming the tip of the actuator which was initially soaked as 12 mm in the electrolyte. The current passing through the actuator was measured with a digital oscilloscope connected with the potentiostat. The images of the PPy actuator were taken with a digital camera.

3. RESULTS AND DISCUSSION

The PPy strip bends in a regular direction upon electrochemical undoping (–0.85 V vs. Ag/Ag^{+}) and reverts upon doping (0.2 V vs. Ag/Ag^{+}) as shown in Figure 1. However, the deformation of actuator upon undoping seems not uniform along the length of the actuator. That is, the portion closer to the electrolyte surface bends more and the tip of the actuator seems almost to be unchanged. This stimulated

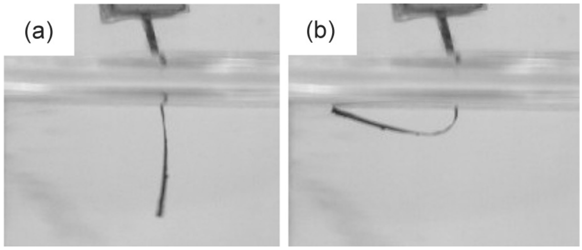

FIGURE 1 Snapshots of a PPy actuator: (a) doped state (0.2 V vs. Ag/Ag^+) and (b) undoped state (–0.85 V vs. Ag/Ag^+).

us to study the size effect or the length dependence of the reduction current, of the actuator. Initially, we have prepared a set of actuators with various lengths to study the size effect. However, the currents passing through the actuators with identical size were found to be far from identical. This is why we used the strategy, changing the length of an actuator by trimming its tip, in this study. Although the experimental results shown in this paper are those collected during undoping, the same tendency was found in data for doping.

Figure 2 shows the temporal change of the reduction current passing through the PPy actuator with various lengths. The current shows

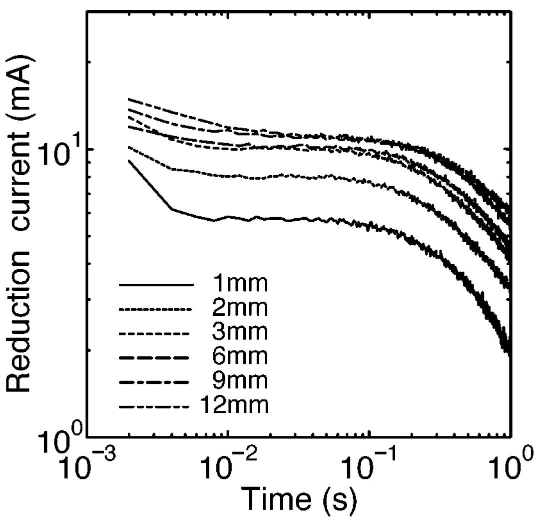

FIGURE 2 Temporal change of the current passing through the actuator with various length upon undoping (reduction).

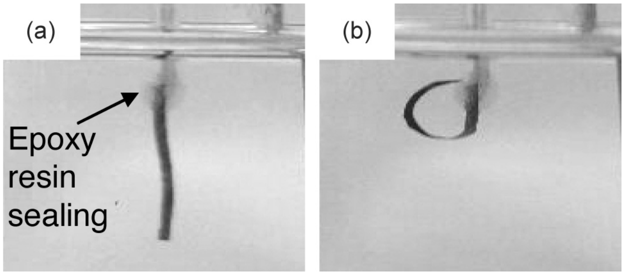

FIGURE 3 Snapshots of a sealed PPy actuator: (a) doped state (0.2 V vs. Ag/Ag^{+}) and (b) undoped state (–0.85 V vs. Ag/Ag^{+}).

no notable change until the actuator was trimmed into 3 mm-length. Therefore, it is expected that only 3 mm portion from the surface of electrolyte was driven as actuator. This may be due to the reduction of conductivity of PPy upon undoping, which makes the tip almost be insulated from the potentiostat.

Figure 1 also suggests another factor to limit the active area of the actuator. It is widely observed that the rate of an electrochemical reaction increases at the electrolyte surface. For example, the rate of electropolishing of a tungsten wire is so fast at the electrolyte surface and the wire is sometimes cut there. Therefore, we have sealed the

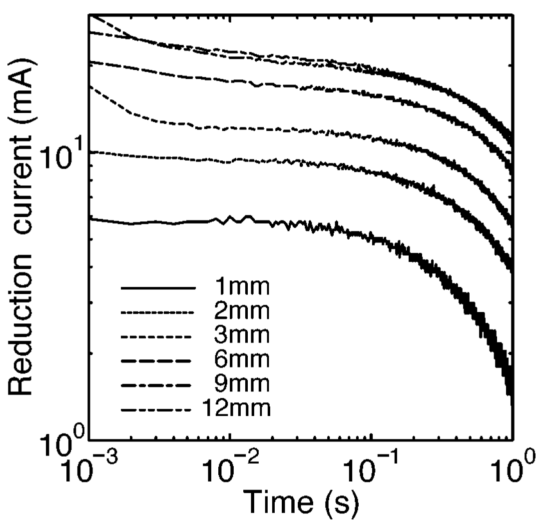

FIGURE 4 Temporal change of the current passing through the sealed actuator with various lengths upon undoping (reduction).

actuator with an epoxy resin to electrically insulate the actuator from the electrolyte surface. The sealed actuator shows more uniform bending, as shown in Figure 3, indicating that the enhancement of the electrochemical process, undoping or reduction in this case, at the electrolyte surface contribute to limit the active area of the PPy actuator as predicted.

However, the size effect of the PPy actuator was not completely removed by the sealing. Figure 4 shows the temporal change of the reduction current passing through the sealed PPy actuator with various lengths. Again, the current shows no notable change until the actuator was trimmed into 6 mm-length. Although the active area doubled from the actuator without sealing, it is suggested that the reduction of conductivity upon undoping limits the active area.

4. CONCLUSIONS

In this paper, the size effect, the length dependence of actuation behavior, of anisotropic PPy film obtained by electrochemical polymerization in a thin slab vessel consisting of PTFE walls, was studied. It was found that the active area of the actuator is limited within 3 mm from the electrolyte surface when it is simply soaked in the electrolyte. The active area is doubled to be 6 mm from the root of the actuator by electrically insulating the actuator from the electrolyte surface. These results suggest that the active area of the PPy actuator is mainly limited by two factors, the enhancement of electrochemical reaction rate at the electrolyte surface and the reduction of electrical conductivity of the actuator upon undoping.

REFERENCES

[1] Pei, Q. & Inganas, O. (1993). *Synth. Met.*, *55–57*, 3718.
[2] Kaneto, K., Takashima, W., Min, Y.-G., & MacDiarmid, A. G. (1995). *Synth. Met.*, *71*, 2211.
[3] Onoda, M., Tada, K., & Nakayama, H. (1999). *Synth. Met.*, *102*, 1321.
[4] Okamoto, T., Tada, K., & Onoda, M. (2000). *Jpn. J. Appl. Phys.*, *39*, 2854.
[5] Tada, K., Kato, Y., & Onoda, M. (2003). *Synth. Met.*, *135–136*, 101.
[6] Kato, Y., Tada, K., & Onoda, M. (2003). *Jpn. J. Appl. Phys.*, *42*, 1458.