Supporting Information

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Polypyrrole Microtubule Actuators for Seizing and Transferring Microparticles

Ximin He, Chun Li, Feng’en Chen, Gaoquan Shi*

Department of Chemistry and The Key Lab of Bioorganic Phosphorous Chemistry & Chemical Biology, Tsinghua University, Beijing 100084, People’s Republic of China

E-mail: gshi@tsinghua.edu.cn

1. Bending Movements of Both Actuators in Aqueous Electrolyte.

The bending movements of the bi-layer beams (15 × 1.5 × 0.025 mm) of actuators 1&2 were studied by cyclic voltammetric scanning in a 1.0 mol L⁻¹ LiClO₄ aqueous solution at a scan rate of 30 mV s⁻¹. The experimental results demonstrated that both actuators can bend from a position of 0° (vertical) to −90° (oxidation) and +90° (reduction) by adjusting driving potentials, and the bending rate can be as high as ~100° s⁻¹ at a driving potential of 0.8 V vs. Ag/AgCl (Fig. S1a). This movement rate is much higher than those of a single-layer anisotropic PPy (DBS) film (~60° s⁻¹ at 1.0 V),[1] the single-layer polyaniline film (~20° s⁻¹ at 1.0 V),[2] and PPy bi-ionic actuators (~30° s⁻¹ at 1.0 V).[3] The charges consumed for the bi-layer beams of actuators 1 and 2 bent to 90° were measured to be about 4.6 and 3.2 mC, respectively (Fig. S1b). Actuator 2 consumed less charge than that of actuator 1 is possibly due to the fact that the very thin gold layer in actuator 2 improved its charge efficiency.
Fig. S1. (a) Plots of movement rates of free-standing PPy bi-layer beams at different driving potentials in the aqueous solution of 1.0 mol L\(^{-1}\) of LiClO\(_4\). ■: Actuator 1, ▲: Actuator 2. (b) plots of the consumed charge versus the applied electrical current density during bending movement of the bi-layer beams at the 15th cycle.


2. SEM Images of the Flat Sides after Actuation.

Fig. S2 shows SEM images of the flat film surface of actuators after actuation in aqueous electrolyte containing PS particles. It is clear that very few particles were adhered onto the flat surface, indicating that the aligned microtubules are specific for seizing the particles.
Fig. S2. SEM images of the flat film surface of actuator 1 (a, b) and actuator 2 (c, d) after actuation in 1.0 mol L\(^{-1}\) LiClO\(_4\) aqueous solutions containing 1 wt\% polystyrene microparticles with diameters of 0.28 (a,c) and 1.14 µm (b, d), respectively. The actuators were actuated by cyclic voltammetric scanning between 0.8 to −1.2 V for 3 cycles at a potential scan rate of 50 mV s\(^{-1}\).

3. Effects of Redox States of the Actuators on the Ability of Seizing Microparticles.

Fig. S3. SEM images of microtubule surface of actuator 2 after electrochemically (a, c) oxidized at 0.2 V (vs Ag/AgCl) and (b, d) reduced at −0.8 V (vs Ag/AgCl) for 30 s after two voltammetric cycles between 0.8 −1.2 V at a potential scan rate of 50 mV s\(^{-1}\) in 1.0 mol L\(^{-1}\) LiClO\(_4\) aqueous solutions containing 1 wt % PS particles with diameters of 0.28 (a, b) and 1.14 µm (c, d), respectively.
4. Effects of Morphology Changes of the Actuators on the Ability of Seizing Microparticles.

Fig. S4. SEM images of microtubule surface of actuator 2 clamped to prevent from bending movement, after electrochemically (a, c) oxidized at 0.2 V (vs Ag/AgCl) and (b, d) reduced at −0.8 V (vs Ag/AgCl) for 30 s after two voltammetric cycles between 0.8 ~ −1.2 V at a potential scan rate of 50 mV s⁻¹ in 1.0 mol L⁻¹ LiClO₄ aqueous solutions containing 1 wt% PS particles with diameters of 0.28 (a, b) and 1.14 µm (c, d), respectively.

5. Experimental Section

Fig. S5. Schematic illustration of the procedure for the fabrication of actuator 1. 1. Chemical polymerization of 0.2 mol L⁻¹ pyrrole within the micropores and on the surfaces of PC membrane by oxidation with an aqueous solution of 0.5 mol L⁻¹ FeCl₃ and 0.5 mol L⁻¹ pTS; 2. Electrochemical deposition a PPy layer on one surface of the composite membrane by direct oxidation 0.1 mol L⁻¹ pyrrole in 0.1 mol L⁻¹ DBSA aqueous solution galvanostatically at 2 mA cm⁻² for 1200 s; 3. Removing the PPy on the other surface of the PC membrane; 4. Dissolving the PC membrane.
**Fig. S6.** Sketch of the cross-sectional view of the device for template guided electrochemical synthesis. **a:** reference electrode; **b:** counter electrode; **c:** Teflon container; **d:** electrolyte; **e:** PC/AAO membrane; **f:** Teflon clamp; **g:** fixing screw; **h:** stainless steel sheet; **i:** vacuum grease; **j:** rubber ring.

**Fig. S7.** Schematic illustration of the procedure for the fabrication of actuator 2. 1. Electrochemical polymerization of 0.1 mol L\(^{-1}\) pyrrole within the micropores of AAO membrane in 0.1 mol L\(^{-1}\) DBSA aqueous solution potentiostatically at 0.8 V for 600 s; 2. Removing the top ~45 µm portion of AAO membrane; 3. Electrochemical deposition a layer of PPy on the surface of thin gold layer of the composite membrane by direct oxidation 0.1 mol L\(^{-1}\) pyrrole in the aqueous solution of 0.1 mol L\(^{-1}\) DBSA galvanostatically at 2 mA cm\(^{-2}\) for 1200 s; 4. Dissolving the AAO membrane.