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Assemble of Polyaniline/Silk Based Electrochemical Textile Transistor (EC-TT)

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ABSTRACT

Polyaniline/silk based wet type electrochemical textile transistor (EC-TT) was assembled. Functions of the EC-TT and triode valve were discussed.

Keywords: electroactive textile, organic textile transistor, polyaniline, redox

Introduction

Polyaniline (PANI) as synthetic metals [1] is one of the most interesting conductive polymers because of convenient synthesis method in the water, good redox property, anti-corrosion function, and good film forming property. We have prepared PANI on the surface of paper or silk. The resultant PANI thus synthesised on the textile has flexibility, strength, and moderate electrical conductivity. This textile can be referred to as "electroactive textile". Up to date, organic transistors have been studied for new type electrochemical transistors [2,3]. Polyethylene dioxythiophene (PEDOT) was mainly used for organic transistors. Recently, organic transistors have developed for biological applications [4]. In the present study, we assemble textile type electrochemical transistor based on PANI. Although switching rate was slow compared to solid state semiconductors, current between two electrodes can be tuned through external voltage based on redox reaction (electrochemically doping-dedoping). This paper reports on assembly of a wet-type textile transistor with no vapor deposition process.

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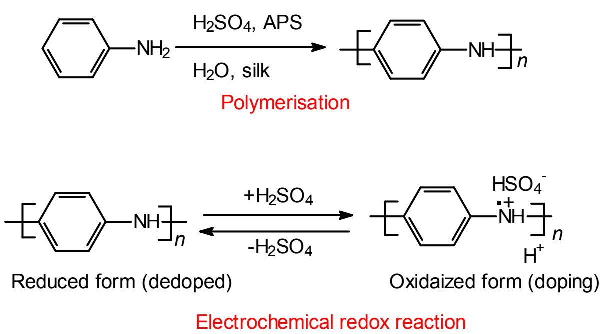
Synthesis of PANI/silk

Aniline as a monomer was polymerised in the presence of silk in the water containing sulfuric acid, ammonium persulfate (oxidiser) for 12 h at ca. 0 °C (Scheme 1). Then, the textile surface was washed with water, and methanol followed by dry in reduced pressure. The PANI layer is deposited on the surface of the silk. The resultant PANI/silk sheet is flat, and easy to process with scissors. Silk, as a substrate of the PANI layer, is obtained from a silk worm.



Scheme 1. Preparation of polyaniline (PANI) in the presence of silk and redox (doping-dedoping) reaction. APS = ammonium persulfate.

Assemble of PANI/silk electrochemical transistor

PANI/silk sheet was fixed on the stainless-steel plate tightly to have good electrical contact between PANI and the plate. PANI/Silk was sandwiched between comb type electrode and the stainless-steel plate as gate. Figure 1 shows schematic illustration of the device. The electrodes have ohmic contact with PANI/silk. Then, sulfuric acid as electrolyte solution (5% in water) and proton-dopant is soaked in the PANI/silk. The electrical circuit is drawn in Figure 2. Although PANI forms various oxidised and reduced forms, a simplified scheme of the redox reaction of PANI is indicated in Scheme 1. Drain (D), and gate (G) and source (S) can be defined in the PANI/silk based device, Figure 1.

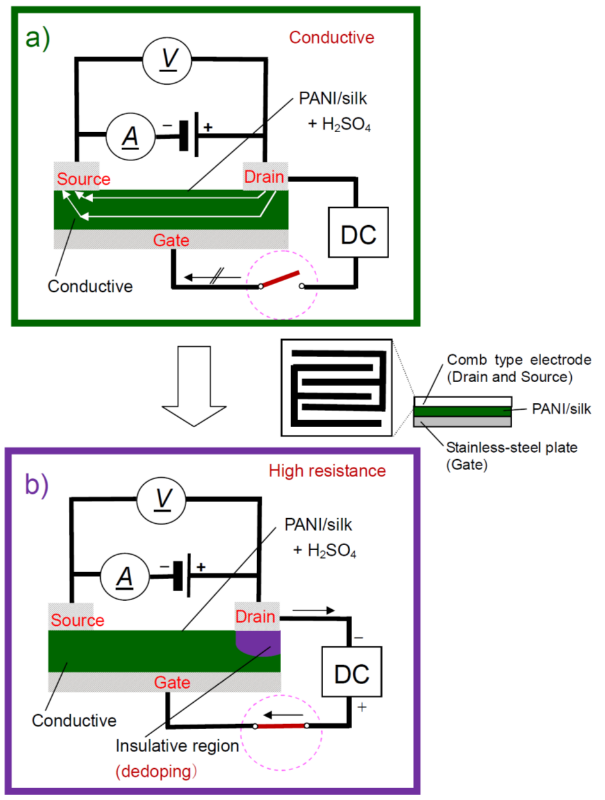


Figure 1. Conceptual diagram of polyaniline (PANI) based electrochemical transistor. (a): Electrical conduction state between drain (D) and source (S). (b): gate (G) voltage driven transition for electrical insulative state between D and S.

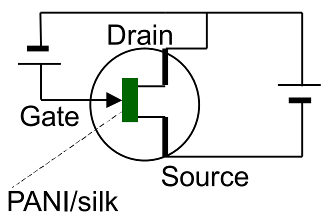


Figure 2. Electrical circuit of PANI/silk based textile transistor.

Function

Resistance (ρ) of drain-source as a function of gate voltage (*E*) for the PANI/silk based EC-TT was measured with two-probe method. Here, 1/ρ is proportional to electrical conductivity (σ), ($1/\rho \propto \sigma$). 1/ρ values between the drain and the source of the EC-TT were decreased with increase of application of gate voltage ($1.2 \times 10^{-7}\ \Omega^{-1}$ (gate = 0 V), $1.9 \times 10^{-8}\ \Omega^{-1}$ (gate = 0.6 V), indicating the gate voltage can tune the drain-source conductivity.

Mechanism

The PANI/silk-based EC-TT device functions based on electrochemical redox (doping-dedoping) on the surface of the gate and the drain part. PANI can be electrochemically doped and dedoped (redox reaction) by applying voltage (Scheme 1). Before application of the gate voltage, PANI/silk (containing sulfuric acid) is conductive state because PANI/silk is doped with sulfuric acid. On the other hand, application of the gate voltage induces electrochemical dedoping at the drain region of PANI/silk layer, resulting transition of the PANI from conductive to insulative state. Therefore, the PANI/silk at the drain region shows high resistance. This function is comparable to that of triode valve, as shown in Figure 3. The PANI/silk at the source region can function as the grid of triode valve, which is electronic shutter for electron movement between the filament and the plate in the triode valve.

As for the triode valve, application of the grid voltage (negative voltage) screened the flow of electrons to the plate. The PANI/silk based electrochemical device tunes its drain-gate conductivity through application of the external gate voltage. In this case, the dedoped (insulative) form of the PANI component functions as a shutter. However, sulfuric acid as electrolyte solution is impregnated in the PANI/silk. So, the element of ionic electrical conduction can not be excluded, resulting the textile device shows ion conductivity after applying the gate voltage. Complete cut-off of the drain-source conductivity was not achieved by the gate voltage. Furthermore, slightly doping is occurred at the source region of the component of the PANI due to the drain-source conduction. This conductivity depresses dedoping at the source, resulting decrease of efficiency of the insulation at the source region.

The gate voltage may allow switching of ionic conduction in the device. In this case, the switching of ionic conduction in the textile transistor contributes switching of the entire electrical conduction system between the source and the drain in addition to the electrical conduction through π-conjugation of PANI, resulting the PANI/silk based devices can tune output flow of electricity.

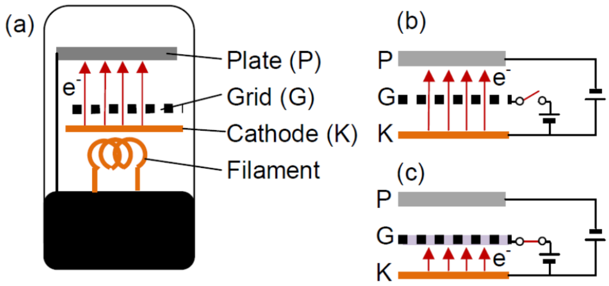


Figure 3. Mechanism of triode valve. (a): Graphical representation of triode valve. (b): Electron flow from cathode (K) to plate (P). (c): Applying negative voltage to grid results screening of electron current from K to P.

Conclusions

Assemble of PANI/silk composite based EC-TT was carried out. The gate voltage tunes electrical conduction between the drain-source conductivity, although high voltage and quick switching can not be achieved at the present stage.

Acknowledgments

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