

CONFERENCE PAPER

NZAAR-EERE-16-43 ICEERE 2016

# Treated Transparent Conducting Films for Full Flexible Electrochromic Devices

Kanyanee Sanglee<sup>1,2</sup>, Surawut Chuangchote<sup>1,2\*</sup>, Pipat Chaiwiwatworakul<sup>1,2</sup>, Pisist Kumnorkaew<sup>3</sup>

<sup>1</sup>The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, 126 Prachauthit Rd., Bangmod, Tungkru, Bangkok 10140, Thailand.

<sup>2</sup>Centre of Excellence on Energy Technology and Environment, Science and Technology Postgraduate Education and Research Development Office, Bangkok Thailand

<sup>3</sup>National Nanotechnology Center, National Science and Technology Development Agency, 111 Thailand Science Park, Phahonyothin Rd., Khlongnueng, Khlongluang, Pathumthani 12120, Thailand

\* Correspondence: surawut.chu@kmutt.ac.th

## PUBLISHED IN

The First NZAAR International Event Series on Natural and Built Environment, Cities, Sustainability and Advanced Engineering  
*International Conference on Environmental Engineering and Renewable Energy (ICEERE 2016)*

|           |                                                       |
|-----------|-------------------------------------------------------|
| Pages     | 104-105 of the volume                                 |
| Held      | 26 June 2016, Shangri-La Hotel, Putrajaya, Malaysia   |
| ISSN      | 2463-5979 (online)<br>2463-5960 (print)               |
| Publisher | New Zealand Academy of Applied Research Ltd, Auckland |

## ABSTRACT

Treatment process by methanesulfonic acid solution was used to improve electrical conductivity of poly 3,4ethylenedioxythiophene:poly(styrene sulfonic acid) (PEDOT:PSS). Weak acid could be used in the treatment because some PSS chains were moved out from the polymer mixer films without damage on the substrates. Variation of number of PEDOT:PSS thin-film layer showed different conductivities. Two layers of treated PEDOT:PSS films were adequate for use as transparent conducting films. Obtained transparent conducting films on polyester substrates were used to fabricate flexible electrochromic devices. The devices showed reversible change in color with switching applied voltages ( $\pm 3$  V). Cyclic voltammetry (CV) and UV-vis-NIR spectroscopy were used to confirm the activity of P3HT/treated-PEDOT:PSS electrode and investigate the light transmission properties of full flexible devices, respectively. .

**Keywords:** Conductivity; Flexible Electrochromic Devices; Methanesulfonic Acid; PEDOT:PSS

## HOW TO CITE

Kanyanee Sanglee, Surawut Chuangchote, Pipat Chaiwiwatworakul and Pisist Kumnorkaew (2016). Treated Transparent Conducting Films for Full Flexible Electrochromic Devices. In *The First NZAAR International Event Series on Natural and Built Environment, Cities, Sustainability and Advanced Engineering*, Putrajaya, Malaysia, 26 June 2016 (pp. 104-105). Auckland: New Zealand Academy of Applied Research. ISSN 2463-5979 (online), 2463-5960 (print).

## TREATED TRANSPARENT CONDUCTING FILMS FOR FULL FLEXIBLE ELECTROCHROMIC DEVICES

Kanyanee Sanglee<sup>1,2</sup>, Surawut Chuangchote<sup>1,2,\*</sup>, Pipat Chaiwiwatworakul<sup>1,2</sup> & Pisist Kumnorkaew<sup>3</sup>

<sup>1</sup>The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, 126 Prachauthit Rd., Bangmod, Tungkru, Bangkok 10140, Thailand.

<sup>2</sup>Centre of Excellence on Energy Technology and Environment, Science and Technology Postgraduate Education and Research Development Office, Bangkok Thailand

<sup>3</sup>National Nanotechnology Center, National Science and Technology Development Agency, 111 Thailand Science Park, Phahonyothin Rd., Khlongnueng, Khlongluang, Pathumthani 12120, Thailand

\*[surawut.chu@kmutt.ac.th](mailto:surawut.chu@kmutt.ac.th)

[www.nzaar.com](http://www.nzaar.com)

### Abstract

Treatment process by methanesulfonic acid solution was used to improve electrical conductivity of poly 3,4-ethylenedioxythiophene:poly(styrene sulfonic acid) (PEDOT:PSS). Weak acid could be used in the treatment because some PSS chains were moved out from the polymer mixer films without damage on the substrates. Variation of number of PEDOT:PSS thin-film layer showed different conductivities. Two layers of treated PEDOT:PSS films were adequate for use as transparent conducting films. Obtained transparent conducting films on polyester substrates were used to fabricate flexible electrochromic devices. The devices showed reversible change in color with switching applied voltages ( $\pm 3$  V). Cyclic voltammetry (CV) and UV-vis-NIR spectroscopy were used to confirm the activity of P3HT/treated-PEDOT:PSS electrode and investigate the light transmission properties of full flexible devices, respectively.

**Keywords:** Conductivity, Flexible Electrochromic Devices, Methanesulfonic Acid, PEDOT:PSS

### 1. Introduction

Electrochromic or smart windows are devices from a group of materials which they can control the amount of light from outside pass through interior of the buildings. Reversible change in color of the devices was occurred after applications of electric current [1]. Most of electrochromic devices are fabricated on glass-based materials which are made from transparent conducting oxide (TCO) substrates. However, TCOs have high cost, poor mechanically flexibility and quite high mechanical brittleness. PEDOT:PSS is a flexible conducting material, but the conductivity of polymer films is still low. Weak acid solution can increase the conductivity of PEDOT:PSS films.

### 2. Literature Review

In many previous reports, the conductivity of PEDOT:PSS films can be improved by treatment processes. The addition of organic compounds, such as ethylene

glycol, dimethyl sulfoxide (DMSO), methanol ( $\text{CH}_3\text{OH}$ ), sulfuric acid ( $\text{H}_2\text{SO}_4$ ), phosphoric acid ( $\text{H}_3\text{PO}_4$ ), etc., leads to increase in conductivity of PEDOT:PSS films to apply in the electrochromic devices [2-4]. In this contribution, the increase of conductivity of PEDOT:PSS thin films by treatment with methanesulfonic acid solution and the use of obtained transparent conducting electrode for fabrication of flexible electrochromic devices are reported. Poly (3-hexylthiophene) (P3HT) and lithium perchlorate ( $\text{LiClO}_4$ ) were used as an electrochromic layer and an electrolyte, respectively. Close devices were fabricated and characterized.

### 3. Research Methods

PEDOT:PSS (PH 1000) aqueous dispersion were coated on polyester substrates with two-time coating by convective deposition method. The coated samples were annealed at  $110^\circ\text{C}$  on a hot

plate for 30 min. PEDOT:PSS films were treated by methanesulfonic acid solution (4 M) by one-time coating. Samples were dried at 110°C on a hot plate again. P3HT solution was coated on the obtained transparent conducting films. The samples were then annealed at 110°C for 60 min in vacuum. Another PEDOT:PSS-coated polyester film was used as a counter electrode of an electrochromic device. Electrolyte 0.1 M of  $\text{LiClO}_4$  was injected into between two electrode films.

#### 4. Discussion and Conclusion

The conductivity of pristine films was about 43 S/cm. For the relationship of conductivity of treated PEDOT:PSS films and number of polymer layers, it was found that the conductivities of 1, 2, 3, 4, and 5 PEDOT:PSS layers were 865, 1064, 1413, 1643 and 2306 S/cm, respectively. Increasing layer of PEDOT:PSS with treatment process showed continuous increase of conductivity of the film samples. It was found that 5 layers of PEDOT:PSS gave the highest electrical conductivity. Although, 5-layer film gave the best conductivity, it was too translucent to be used in the actual electrochromic applications. Weak acid can be induced to increase conductivity of PEDOT:PSS films because some PSS chains are moved out from the polymer mixer films without damage on the substrates [2,3]. The cyclic voltammogram of P3HT/treated-PEDOT:PSS electrode were performed in three-electrode system using 0.1 M  $\text{LiClO}_4$  in an aqueous solution with a scan rate of 0.02 V/s. The reversible oxidation/reduction processes of 1 to 3 cycles of CV were found between 0.25 and 2.0 V. All anodic peaks continually slowly decreased after increased a scan number, because the normal film, purple color, was swollen on surface of substrates. However, this change can be recurrent many of times with no obvious difference. The transmittance spectra of flexible electrochromic device are demonstrated

before applied voltage, the normal state of device gave the transmittance spectra around 20% at 500-600 nm. When the voltage was applied at 3.0 V, transmission of oxidized state increased to 35%.

#### 5. References

- [1] Zmija, J. and Malachowski, M.J. (2011), New organic electrochromic materials and their applications. *Journal of Achievements in Materials and Manufacturing Engineering*, 48/1: pp. 14-23.
- [2] Ouyang, J. (2013), Solution-Processed PEDOT:PSS Films with Conductivities as Indium Tin Oxide through a Treatment with Mild and Weak Organic Acids. *ACS Applied Materials & Interfaces*, 5(24): pp. 13082-13088.
- [3] Xia, Y., Sun K. and J. Ouyang, (2012), Solution-Processed Metallic Conducting Polymer Films as Transparent Electrode of Optoelectronic Devices. *Advanced Materials*, 24(18): pp. 2436-2440.
- [4] Meng, W., Ge, R., Li, Z., Tong, J., Liu, T., Zhao, Q., Xiong, S., Jiang, F., Mao, L. and Zhou Y. (2015), Conductivity Enhancement of PEDOT:PSS Films via Phosphoric Acid Treatment for Flexible All-Plastic Solar Cells. *ACS Applied Materials & Interfaces*, 7(25): pp. 14089-14094.