Sensors & Transducers
Published by IFSA Publishing, S. L., 2017
http://www.sensorsportal.com

Conducting Polymer PEDOT:PSS: An Emerging Material for Flexible and Transparent Electronics

[1*] Anupama CHANDA, [2] Shalik Ram JOSHI,
[3] Rakesh SAHOO, [2] Shikha VARMA, [4] Kwangsoo NO
[1] Dr. H. S. Gour Central University, Sagar-470003, M. P, India
[2] Institute of Physics, Bhubaneswar-751005, Odisha, India
[3] Institute of Minerals and Materials Technology, Bhubaneswar-751013, Odisha, India
[4] KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea
[1] Tel: 07582265459
[*] E-mail: anupamamatsc@gmail.com

Received: 9 January 2017 /Accepted: 3 March 2017 /Published: 31 March 2017

Abstract: A one dimensional variable range hopping type conduction is observed in Poly (3, 4-ethylenedioxythiophene): polystyrenesulfonate (PEDOT:PSS) films obtained by a spin coating technique on polyethylene naphthalate (PEN) substrate and the mechanism behind enhancement in conductivity in 3 % dimethyle sulfoxide (DMSO) doped PEDOT:PSS film is due to the phase segregation of PSS on the surface and reduction of energy barrier between the conducting grains. Enhanced conductivity of PEDOT:PSS films and transparency more than 80 % in the visible region makes PEDOT:PSS films suitable for flexible and transparent optoelectronic devices.

Keywords: PEDOT-PSS, Conductivity, Variable range hopping, XPS, UV-Vis.

1. Introduction

In the recent years there has been an increasing interest in the field of organic electronics due to its light-weight, high flexibility, and easy processability. Indium-tin oxide (ITO) has been widely used as the transparent electrode in flexible devices, but due to its limitation in mechanical flexibility, large use and high cost there is a great demand for an alternative solution like organic based electrodes with both high transparency and high conductivity. Poly (3,4-ethylenedioxythiophene): polystyrenesulfonate (PEDOT : PSS) has been emerged as a promising material in the field of optoelectronic devices due to its high conductivity and transparency along with other attractive polymer properties like the ease of synthesis and high degree of flexibility [1-3]. It has been widely used as a buffer layer in organic electronics. It has a higher work function (5.2 eV) over ITO (4.5-5.14 eV). Great effort has been given to research to get higher luminous intensity and higher external efficiency in the Organic Light Emitting Diodes (OLEDs) using PEDOT:PSS anode [4, 5]. Although, commercially available PEDOT : PSS (Baytron P, Bayer Corporation) has a conductivity of less than 1 S/cm, recently, it is observed that the conductivity of PEDOT : PSS (PH-1000) films can be enhanced by three orders of magnitude by undergoing different processing steps or by doping with various additives [6-9]. There are several reports on the mechanism of enhanced conductivity of PEDOT:PSS due to additives, but the subject is still under debate. In this study, we obtain conductivities as high as 980 S/cm for PEDOT:PSS (PH1000 from H. C.Starck) with the addition of 3 at% Dimethyl sulfoxide (DMSO) and the mechanism of conductivity enhancement is explained by taking into theoretical consideration along with X ray Photoelectron Spectroscopy (XPS) study.

2. Experimental

2.1. Materials and Methods

In this work PEDOT:PSS (Clevios PH1000, Heraeus Clevios GmbH, Germany) was used as the starting material to which DMSO (3 at%) (Sigma-Aldrich) was added and mixed well before deposition. Films were deposited on glass substrates by using a spin coating technique (4000 rpm, 40 sec) and after deposition, films were annealed at 140 °C for 1h in the air. Before deposition of the films, oxygen plasma treatment (for 3 min at 100 Watt) was carried out on the substrates to increase the adhesion of the films.

2.2. Characterization

After deposition and annealing of the films, the temperature dependent resistivity measurement of the films was performed using four probe method and the transmittance study was done from UV-Visible spectra using Shimadzu UV-VIS spectrophotometer. XPS analysis was carried out in a VG Microtech-ESCA2000 Multilab instrument to study the chemical states of the surface.

3. Results and Discussion

Fig. 1 shows the transmittance spectra of undoped and 3 % DMSO doped PEDOT:PSS films taken from a UV-Visible spectrophotometer. Transmittance of more than 80 % in the visible region in 3 % DMSO doped PEDOT:PSS films was observed from UV-Visible spectra. Fig. 2 indicates conductivity versus temperature plot obtained by a four probe method and the data were fitted with a function [10]

$$\sigma = \sigma_0 e^{-\left(\frac{T_0}{T}\right)^{\alpha}} \quad (1)$$

where σ is the conductivity at temperature T and σ_o is the conductivity at infinite temperature. α = 1/(1+D) denotes the signature of variable range hopping for D dimension. T_o is the effective energy barrier for hopping of charge carriers between localized states. The corresponding parameters obtained after fitting the experimental data with the above function is given in Table 1 from which the value of α is found to be 0.48 for 3 % DMSO doped PEDOT:PSS films giving D=1.08 which indicates one dimensional hopping conduction mechanism is suitable for the films. The conductivity at room temperature is observed to be enhanced 4 orders of magnitude in 3% DMSO doped films as compared to undoped PEDOT:PSS films. Also, it is noted that T_o drops (from 1940 to 305) by the addition of DMSO suggesting that the effective energy barrier for 3% doped film is decreased which leads to an increase in conductivity. In Fig. 2 solid line (black) indicates the experimental plot and dash line (red) indicates the fitted plot.

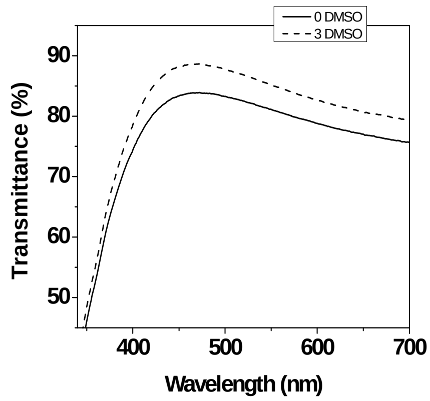

Fig. 1. Transmittance spectra of undoped and 3 % DMSO doped PEDOT:PSS films.

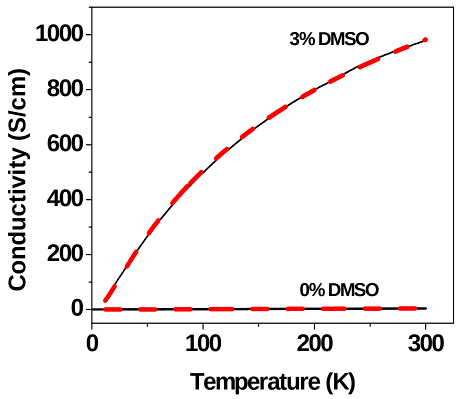

Fig. 2 Temperature versus conductivity of PEDOT:PSS films.

Table 1. Parameters obtained using Eq. (1).

DMSO (%)	σ_{300}(S/cm)	σ_0 (S/cm)	α	T_o (K)
0	0.1	38	0.42	1940
3	980	2690	0.48	305

Fig. 3 (a, b) shows the XPS spectra of sulphur for undoped and 3 % DMSO doped PEDOT:PSS films along with its deconvolution. It can be seen from the deconvoluted spectra that various components of S ($2p_{3/2}$, $2p_{1/2}$) signal are coming from PEDOT, PSS-, PSSNa, PSSH. From the spectra PEDOT to PSS ratio was calculated and was found to be decreased from 3.7 for pristine to 2.91 for 3 % DMSO doped films which indicates phase segregation with an excess of PSS on the surface. The increase in conductivity due to 3 % DMSO doped film is associated with the reduction of insulating PSS shell surrounding conducting PEDOT grains and maintaining a good connection between the PEDOT grains. This enhances the transportation of carriers between the PEDOT grains easy which in turn increases the conductivity.

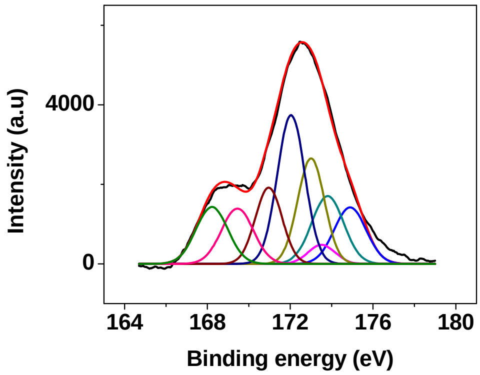

Fig. 3 (a) XPS spectra of undoped PEDOT:PSS film.

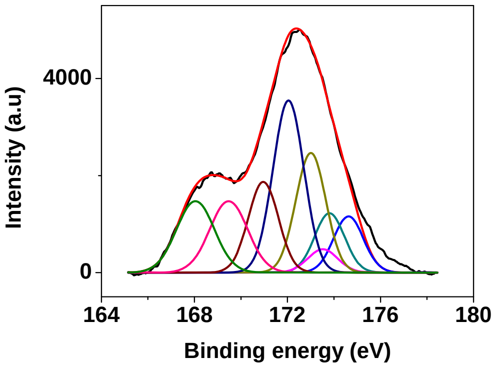

Fig. 3 (b) XPS spectra of 3 % DMSO doped PEDOT:PSS film.

4. Conclusion

In conclusion, a one dimensional variable range hopping type conduction is observed in PEDOT:PSS films and the mechanism behind enhancement in conductivity in 3 % DMSO doped PEDOT:PSS film is due to the phase segregation of PSS on the surface and reduction of energy barrier between the conducting grains. Enhanced conductivity of PEDOT:PSS films and transparency more than 80 % in the visible region makes PEDOT:PSS films suitable for flexible and transparent optoelectronic devices.

Acknowledgements

The first author (Anupama Chanda) would like to acknowledge UGC for providing financial support from Start-up grant project to carry out the research.

References

[1]. G. Hewang and F. Jonas, Poly (alkylenedioxythiophene)s - new, very stable conducting polymers, *Advance Functional Materials*, Vol 4, Issue 2, 1992, p. 116.

[2]. L. B. Groenendaal, F. Jonas, D. Freitag, H. Pielartzik, and J. R. Reynolds. Poly(3,4-ethylenedioxythiophene) and its derivatives: past, present, and future, *Advanced Materials*, Vol. 12, Issue 7, 2000, pp. 481–494.

[3]. Q. Pei, G. Zuccarrelo, M. Ahlskogt, O. Inganas. Electrochromic and highly stable poly(3,4-ethylenedioxythiophene) switches between opaque blue-black and transparent sky blue, *Polymer*, Vol. 35, Issue 12, 1994, pp. 1347.

[4]. K. Fehse, K. Walzer, K. Leo, W. Lovenich and A. Elschner. Highly Conductive Polymer Anodes as Replacements for Inorganic Materials in High-Efficiency Organic Light-Emitting Diodes, *Advance Materials*, Vol. 19, Issue 3, 2007, pp. 441.

[5]. M. Vosgueritchian, D. J. Lipomi and Z. Bao. Highly conductive and transparent PEDOT: PSS films with a fluorosurfactant for stretchable and flexible transparent electrodes, *Advance Functional Materials*, Vol. 22, Issue 2, 2012, pp. 421.

[6]. B. P. A. Levermore, L. Chen, X. Wang, R. Das and D. D. C. Bradley. Fabrication of Highly Conductive Poly(3,4-ethylenedioxythiophene) Films by Vapor Phase Polymerization and Their Application in Efficient Organic Light-Emitting Diodes, *Advance Materials*, Vol. 19, Issue 17, 2007, pp. 2379.

[7]. Y. H. Kim, C. Sachse, M. L. Machala, C. May, L. Muller- Meskamp and K Leo, Highly Conductive PEDOT:PSS Electrode with Optimized Solvent and Thermal Post-Treatment for ITO-Free Organic Solar Cells, *Advance Functional Materials*, Vol. 21, Issue 6, 2011, pp. 1076.

[8]. D. Alemu, H. Y. Wei, K. C. Ho and C. W. Chu, Highly conductive PEDOT: PSS electrode by simple film treatment with methanol for ITO-free polymer solar cells, *Energy Environmental Science*, Vol. 5, Issue 11, 2012, pp. 9662.

[9]. D. A. Mengistie, M. A. Ibrahem, P. C. Wang, and C. W. Chu. Highly conductive PEDOT:PSS treated with formic acid for ITO-free polymer solar cells, *ACS Applied Materials Interfaces*, Vol. 26 , Issue 6, 4, 2014, pp. 2292.

[10]. N. Mott and E. A. Davis, Electronic Processes in Non Crystalline Materials, *Clarendon Press*, Oxford, 1979.