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Growth of Cu_2O on TCO by SILAR Method acts as an Alternative Buffer Electrode Layer Towards the Development of Organic Solar Cell

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Abstract

In many types of optoelectronic devices, layer of PEDOT: PSS is sandwiched between the indium-tin oxide (ITO) electrode and the active layer. Buffer PEDOT: PSS provides a well-defined work function which is higher than that of ITO (4.2eV), it smooths the ITO surface and so avoids shorts, and it also protects the active layer from ingress of indium or oxygen, leading to longer device lifetimes. The role of PEDOT: PSS is enormous. Unfortunately, PEDOT: PSS colloidal solution is strongly acidic and the PSS is strongly hygroscopic, which has the potential to cause degradation in adjacent layers, if water is not removed completely. Here to smooth the surface of ITO and to improve the durability of the device a buffer layer of Cu_2O has newly been introduced, adopting SILAR method on ITO. A qualitative comparison has been performed with Cu_2O buffer layer to the most familiar PEDOT: PSS buffer layer. The thorough characterization of both the buffer materials are performed by XRD and UV-Vis transmittance spectroscopy. The surface morphology has been analyzed by AFM. Finally, the influence of buffer layer on energy conversion efficiency has been tested for the MEH-PPV/PCBM based organic solar cell, by fabricating the device of configuration ITO/buffer-material/ MEH-PPV/PCBM/Aluminium. The improvement in open circuit voltage and light conversion efficiency implied the potential applicability of Cu_2O over PEDOT: PSS as buffer electrode layer.

Keywords: SILAR Method, buffer layer, organic solar cell, growth of Cu_2O.

INTRODUCTION

In many types of optoelectronic devices, layers of PEDOT: PSS are sandwiched between the indium-tin oxide (ITO) electrode and the active organic layer. The role of PEDOT: PSS is enormous. It provides a well-defined work function which is higher than that of ITO, it smooths the rough ITO surface and so avoids shorts, and it protects the active layer from ingress of indium or oxygen, leading to longer device lifetimes [1-2]. Unfortunately, the special nature of this material brings some disadvantages as well. The PEDOT: PSS colloidal solution is strongly acidic and so has the potential to cause degradation in adjacent layers, if water is not completely removed. The morphology of the colloidal particles is gel-like, and they tend, due to the strongly hygroscopic PSS, to swell or shrink considerably, depending on humidity [3]. During film formation under certain conditions, excess PSS from the colloidal solution seems to form a closed surface layer, which increases the work function but also considerably decreases the perpendicular conductivity. These effects influence the final device performance considerably and therefore have been the focus of extensive research in recent years.

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A wide range of different approaches have been carried out to deal with these problems. One of the most prominent methods is the introduction of secondary dopants, additional to PSS, e.g. in the form of polyols or anionic surfactants, changing film-forming properties, water uptake, or work function. Different kinds of chemical modification include modifying the PEDOT: PSS colloidal solution with surfactants or organic solvents to suppress screening effects or improve wet ability [4, 5]. Thermal treatments of PEDOT: PSS films have also been studied, although there is contradictory evidence as to whether these assist or reduce the formation of a PSS-enriched surface layer. Other reported results include enhancement of PEDOT crystallinity, changes in surface roughness, diffusion of indium into PEDOT:PSS, or rupture of the ionic bonds between PEDOT and PSS due to annealing. Nevertheless, fewer efforts have been made to investigate influences of annealing on the PEDOT:PSS complex itself, preheating effects on the colloidal solution, variation of film thickness, and their consequences for device operation [6].

PEDOT:PSS/ITO is a commonly used anode in OLEDs and organic solar cells. The work function of PEDOT:PSS is independent of the work function of the substrate, so that the use of PEDOT:PSS is promising for reproducible fabrication of OLEDs with good performance. In organic solar cells, PEDOT:PSS layer ensures improved interfaced between the active layer and the electrode. Use of PEDOT:PSS also changes the shape of EQE curve, which was attributed to the doping of the active layer by PSS. It was found that the use of PEDOT:PSS increased the yield. The best efficiency reported up to date for a small molecular solar cell of 2.6% was obtained for a device structuring using PEDOT:PSS [7]. However, it was also reported that the use of PEDOT:PSS causes an increase in the series resistance of the solar cell, which results in a lower fill factor. The contradiction between different works on the influence of PEDOT:PSS on the solar cell performance may be due to the fact that the device performance is dependent on the PEDOT:PSS thickness, and that PEDOT:PSS properties are dependent on the thermal treatment. During film formation under certain conditions, excess PSS from the colloidal solution seems to form a closed surface layer, which increases the work function but also considerably decreases the perpendicular conductivity. These effects influence the final device performance considerably and therefore have been the focus of extensive research in recent years [8-10].

In this present experimental study, the influence of buffer layer on energy conversion efficiency of the MEH-PPV: PCBM bulk heterojunction solar cell was investigated and compared aptly by employing Cu_2O thin layer and PEDOT: PSS as buffer layer separately. Here, PEDOT: PSS and Cu_2O as buffer reagent were deposited on ITO coated substrate individually, by introducing two different techniques, (i) spin coating and (ii) sequential ionic layer adsorption and reaction respectively, on which the main active MEH-PPV(donor):PCBM (acceptor) composite was spin coated to fabricate bulk heterojunction solar cells. The material characterizations of the PEDOT:PSS and Cu_2O thin films on ITO coated substrate were performed with XRD, UV-Vis transmittance. The surface morphologies were recorded by AFM. The main bulk heterojunction was formed by incorporating PCBM, organic acceptor polymer in conjunction with MEH:PPV organic donor polymer. Finally, three bulk heterojunction solar cells with configuration ITO/MEH-PPV:PCBM/Al; ITO/PEDOT:PSS/ MEH-PPV:PCBM /Al and ITO/Cu_2O/ MEH-PPV:PCBM /Al were fabricated and characterized, successfully [11].

EXPERIMENTAL

Reagents

The experimental reagents $CuSO_4$, $Na_2S_2O_3$, NaOH, NH_4Cl of AR grade and Acetone, Ethanol and 1-2 Dichlorobenzene of GR grade were purchased from Merck and were used without further purification. The transparent buffer material PEDOT:PSS was purchased from Sigma Aldrich. To fabricate the main active layer of bulk heterojunction solar cells, MEH:PPV and $PC_{60}BM$ were purchased from Sigma Aldrich. All the chemicals were used without further purification [12].

Chemical Growth of Cu_2O Buffer Layer and its' Characterizations

Indium tin oxide (ITO) coated glass was cleaned with distilled water, acetone and ethanol repeatedly in ultrasonic bath. Then it was dried under vacuum at 70°C before preparing thin buffer layer on to the

substrate. On other hand, 100ml 0.1M aqueous solution of $CuSO_4$ and 400ml 0.1M aqueous solution of $Na_2S_2O_3$ was prepared separately. Aqueous solution of sodium-thiosulfate was mixed with 100 ml $CuSO_4$ solution dropwise, until the mixture become colorless. In another beaker 100ml of 0.1M aqueous solution of NaOH was prepared separately. The pre-cleaned ITO coated glass substrate was firstly immersed into NaOH solution for 3 to 4 seconds then it was dipped into the previous mixture for next 5 seconds. The chemical reaction scheme is furnished as:

$$Cu^{2+} + SO_4^{2-} + Na^+ + S_2O_3^{2-}$$
$$\downarrow$$
$$Cu^+ + Na^+ + S_4O_6^{2-}$$
$$\downarrow$$
$$Cu_2O + S_2O_3^{2-} + Na^+ + H_2O$$

This process was performed twice repeatedly and periodically, until a reddish-yellow layer was deposited on to the ITO. The back side of the substrate was cleaned by NH_4Cl solution. As the uniform transparent reddish yellow layer was appeared, the substrate was heated to 100°C under vacuum oven. Thereafter it was ready to prepare the thin active layer of the device on to. This substrate was characterized by XRD and AFM. To study the transparency, the transmittance spectrum was recorded with UV-Vis spectrophotometer [13].

Deposition of PEDOT:PSS Buffer Layer and its' Characterizations

The spin coating technique was adopted in preparation of PEDOT:PSS thin layer. The precleaned ITO coated glass, washing with distilled water, acetone and alcohol repeatedly was taken as the substrate. PEDOT:PSS, purchased from sigma Aldrich, was spun on to the substrate at 600rpm for 2minutes and thereafter 1400 rpm for next 10 minutes with the help of SCU2007 spin coating unit. As a thin uniform film of PEDOT:PSS was observed, it was transferred to the vacuum chamber, maintained temperature at 100°C for drying. This substrate was characterized by XRD; AFM and UV-Vis spectrophotometer.

ITO Coated Substrate Without Buffer Layer and Characterizations

ITO coated glass was washed with distilled water, acetone and ethanol repeatedly by ultra-sonication technique. As the cleaning process completed it was dried under vacuum oven at temperature 100^0C to make it ready for fabrication the active layer of the device.

These three ITO coated substrates with buffer layer Cu_2O, with buffer layer PEDOT:PSS and without any buffer layer, for convention were labeled as substrate S1, S2 and S3 respectively.

Fabrication of solar cells

0.1mg of procured MEH-PPV was dissolved in 10ml 1-2 dichlorobenzene by ultra-sonication technique. $PC_{60}BM$ solution was prepared by dissolving 0.1mg into 10ml 1-2, dichlorobenzene under vigorous stirring for 10 minutes. As ready active layer in prior to fabrication of solar cell, MEH-PPV and $PC_{60}BM$ solutions were mixed at wt. ratio 2:1 and stirred for half an hour. As the desire mixture was obtained, was spun on to the pre-prepared substrates one after another on substrate (S1), substrate (S2) and substrate (S3) sequentially, at 600rpm for 2minutes and thereafter 1800 rpm for consecutive 10 minutes with the help of SCU2007 spin coater. As the thin active layer was deposited onto the substrates, were transferred to a vacuum oven for drying at 80^0C. Aluminum electrode was used as a cathode on thin film, was deposited on to the active layer by thermal evaporation technique through shadow mask. To avoid the impact of ambient constraints as well as various contaminations, the samples were prepared under identical conditions. Keithley 2635B source meter was used to study the Current –Voltage (I–V) characteristics of the ready devices under dark and white light illumination (100 mW/cm^2) conditions. Vapor deposition of Aluminum electrodes were carried out by 12A4D HHV Vacuum coating unit. The device architecture is schematically presented in Figure 1.

Instrumentations

The structural characterization of the thin film grown on ITO substrate was done using powder X-ray diffractometer (PXRD) (Bruker D8 Advance X-Ray Diffractometer). Optical properties of the film was characterized using Lambda 365+ Perkin Elmer spectrophotometer in 300-800 nm wavelength range. Surface Morphology was studied using Bruker MultiMode 8 NanoScope V Atomic Force Microscope (AFM) under suitable condition. Vapor deposition of Aluminum electrodes were carried out by 12A4D HHV Vacuum coating unit. Current -Voltage characteristics of the device was measured under dark and white light illumination using Keithley 2635B source meter.

RESULTS AND DISCUSSIONS

Figure 2 represents the XRD pattern of ITO substrate with Cu_2O as buffer layer (blue), with PEDOT:PSS as buffer layer (red), and without any buffer layer (black). The diffraction responsible Braggs' planes for ITO were determined with the JCPDS card no.: 71-2194 and Cu_2O by Card No.:05-0667. There were no external peak for PEDOT:PSS compound.

Figure 3 illustrates the Atomic Force Microscopic (AFM) images of the buffer surfaces. From the images it was noted that the thickness of the as deposited buffer layer is quite thin for Cu_2O (deposited by SILAR method) whereas it is thick for spin coated PEDOT:PSS.

Figure 4(a) represents the UV-Vis transmission spectra of the buffer materials. These transmittance spectra of the buffer thin layers, PEDOT:PSS and Cu_2O were recorded by considering ITO as the reference with the help of Lambda 365+ Perkin Elmer spectrophotometer. The spectrum was recorded from 300nm to 800nm for both the buffer materials. It was observed that for PEDOT:PSS buffer material, the transmittance was higher at higher photon energy spectrum than that of Cu_2O buffer materials. Whereas within visible wavelength the transmittance of Cu_2O was accountable in compare to PEDOT:PSS. In subject of selection mode to apply within solar cell Cu_2O also had potential impact in compare to PEDOT:PSS buffer material. As the absorption of the material is inversely related to transmittance, therefore Cu_2O buffer is more appropriate than PEDOT:PSS in concern to fabricate photovoltaic devices. The absorption coefficient α was determined by employing Beer-Lambert's equation as [14]:

$$\alpha = \frac{2.303}{t} \log \frac{1}{T} \quad (1)$$

where T is transmittance and t is the thickness of the film. Figure 4(b) represents the variation of absorption coefficient with respect to incident energy.

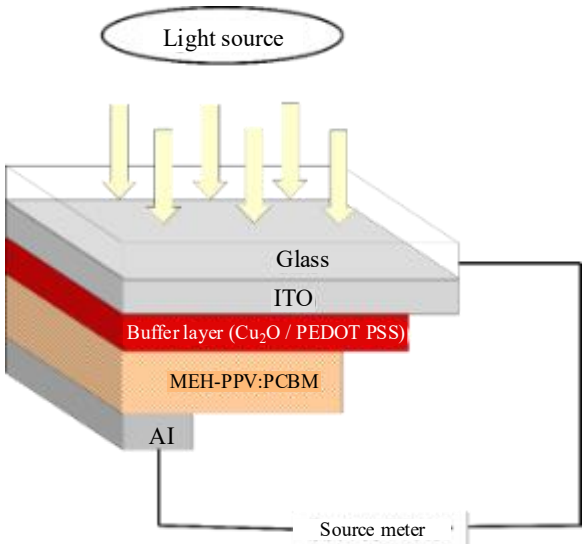

Figure 1. Schematic diagram of fabricated solar cell.

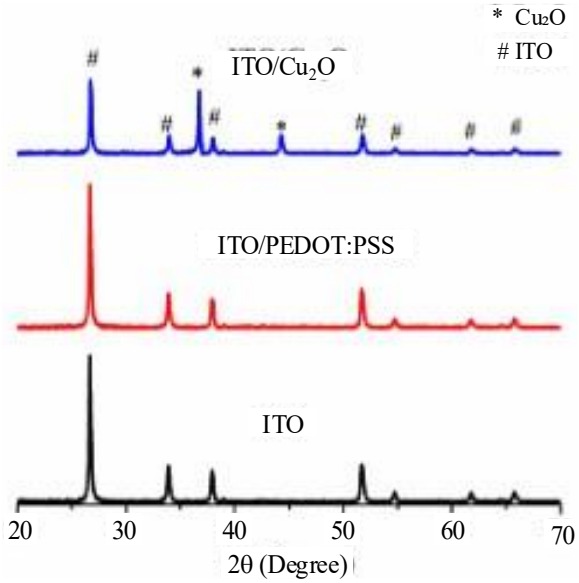

Figure 2. XRD pattern of ITO with and without buffer layers.

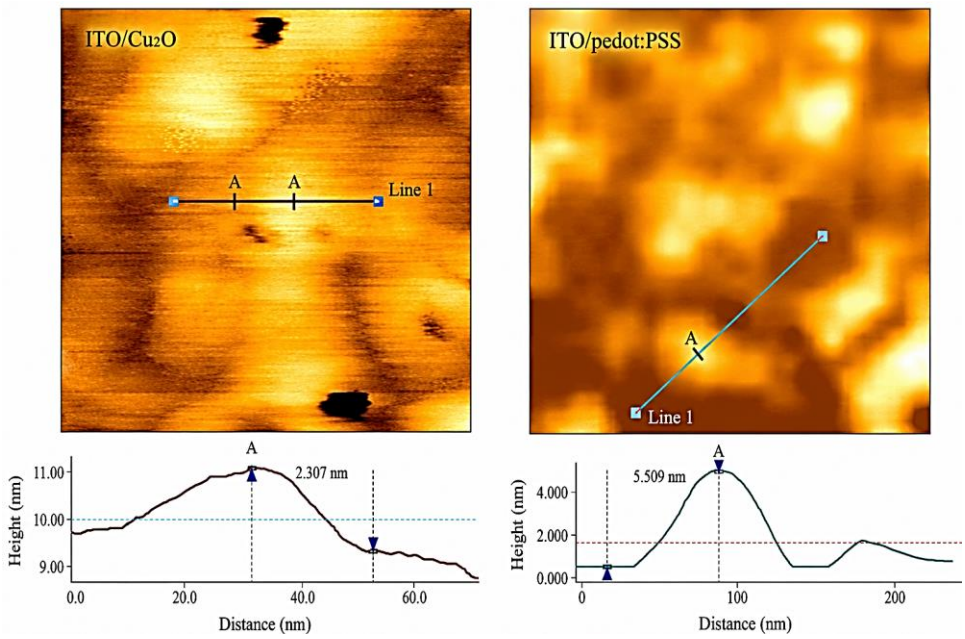

Figure 3. AFM images of as deposited buffer layers.

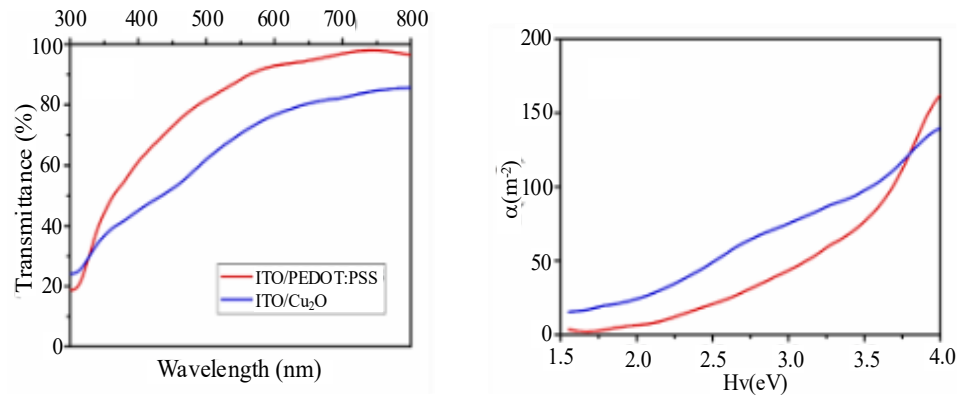

Figure 4. (a) Transmittance spectra; (b) α vs hν plot.

The J-V characteristics under solar irradiation (100mW/cm^2) for three different composition of devices on substrate S1, S2 and S3 are shown in Fig. 5(a). The open-circuit voltage (Voc) and Short circuit current density (Jsc) directly contributes to the power conversion efficiency (PCE) of the device.

The characteristic parameters are extracted from the curves using the following relation [15]:

$$FF = \frac{J_{max} \times V_{max}}{J_{SC} \times V_{OC}} \tag{2}$$

$$PCE = \frac{P_{max}}{P_{in}} = FF \frac{V_{OC}\ J_{SC}}{P_{in}} \tag{3}$$

Figure 5 shows that after introducing PEDOT:PSS and Cu_2O as two distinct buffer layers upon ITO the open circuit voltage of the device has improved from 350mV to 450mV and to 490mV sequentially. It is interesting to note that the short circuit current has not been improved at all for the device fabricated on Cu_2O buffer, but it is improved from 19.32mA/cm^2 to 20.09mA/cm^2 for the device based on PEDOT:PSS buffer. The Fill Factors (FF) are measured for the devices from the characteristic J-V curves are 0.369, 0.503, and 0.504 respectively, which implies that after incorporation of Cu_2O and PEDOT:PSS as buffer materials within the device, FF is improved significantly. Noteworthy, the value of fill factor for both the devices on substrate S1 with comparison to device on substrate S2, don't reflects any change, even while the short circuit current is reduced, after while increase in open circuit voltage. The measured value of J_{sc} and V_{OC} for all respective devices are tabulated in Table-I. The carrier transport dynamics under light irradiance and the ambiguities within thin films, occurred during preparation or formation of junctions are analyzed by estimating effective series and shunt resistances from the characteristics J-V curve (Figure 5(a)). The measured R_s and R_{sh} are tabulated in Table-I. For ideal solar cell the theoretical value of series resistance is zero and the shunt resistance is infinite. The results show that after incorporating buffer medium the series resistance of the cell is reduced whereas the shunt is increased, which signifies the better performance, impact upon power conversion efficiency as well as the transport dynamics of excitons. The increase in shunt resistance and decrease in series resistance, after introducing PEDOT:PSS, are obvious. Meanwhile, here after introducing the inorganic Cu_2O as buffer layer, the series resistance of the cell is also being reduced to 8.3 Ω cm^2 which is lesser than cell developed on bare ITO and higher than cell fabricated on substrate S2. On the other hand, the improvement in shunt resistance is comparably commensurate with the device, make on S2. Figure 5(b) represents the variation of power density against bias voltage.

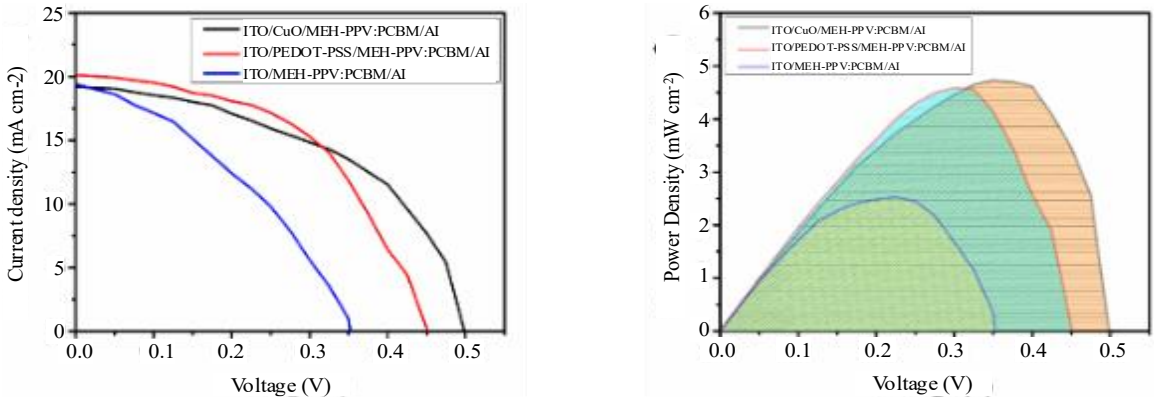

Figure 5. (a) J-V characteristics; (b) Power density against voltage plot.

Table 1. Characteristic parameters of solar cells.

Sample Name	J_{SC} (mAcm^{-2})	V_{OC} (V)	P_{max} (mWcm^{-2})	(FF)	PCE (%)	R_s (Ω cm^2)	R_{sh} (Ωcm^2)
ITO/MEH-PPV: PCBM/Al	19.32	0.35	2.5	0.369	2.5	9.4	42
ITO/PEDOT:PSS/MEH-PPV: PCBM/Al	20.09	0.45	4.56	0.504	4.56	5.5	159
ITO/Cu_2O/MEH-PPV:PCBM/Al	19.12	0.49	4.72	0.503	4.72	8.3	140

CONCLUSIONS

The present work of designing a new inorganic buffer layer is an approach toward the finding of a transformative technology for the construction of MEH-PPV: PCBM organic solar cells. The impact of buffer layer on energy conversion efficiency, as well as on parasitic resistance in concern to excitons transport dynamics of the MEH-PPV: PCBM bulk heterojunction solar cell is investigated and compared appositely by employing Cu_2O thin layer and PEDOT: PSS thin layer as buffer on ITO distinctly. In concern to electrode buffer layer, computing real-time data and analysis of results implies that the Cu_2O layer developed by SILAR technique can be an inexpensive alternative of organic buffer materials, and a potential buffer electrode towards the development of efficient organic solar cells.

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CRediT Authorship Contribution Statement

Asmita Patra: Conceptualization, Formal analysis, Data curation, Writing - original draft, Writing - review & editing. Suman Mahata: Data curation, Formal analysis, Writing - review & editing. Animesh Layek: Funding acquisition, Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing.

Conflicts of Interest

Authors whose names are listed immediately below the title of this article, certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria, educational grants, participation in speakers' bureaus, membership, employment, consultancies, stock ownership, or other equity in interest, and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

REFERENCES

1. Greczynski G, Kugler T, Keil M, Osikowicz W, Fahlman M, Salaneck WR. Photoelectron spectroscopy of thin films of PEDOT–PSS conjugated polymer blend: a mini-review and some new results. Journal of Electron Spectroscopy and Related Phenomena. 2001 Dec 1;121(1-3):1-7.
2. Pingree LS, MacLeod BA, Ginger DS. The changing face of PEDOT: PSS films: substrate, bias, and processing effects on vertical charge transport. The Journal of Physical Chemistry C. 2008 May 29;112(21):7922-7.
3. Fan B, Mei X, Ouyang J. Significant conductivity enhancement of conductive poly (3, 4-ethylenedioxythiophene): poly (styrenesulfonate) films by adding anionic surfactants into polymer solution.
4. Huang J, Miller PF, Wilson JS, De Mello AJ, De Mello JC, Bradley DD. Investigation of the effects of doping and post-deposition treatments on the conductivity, morphology, and work function of poly (3, 4-ethylenedioxythiophene)/poly (styrene sulfonate) films. Advanced functional materials. 2005 Feb;15(2):290-6.
5. Kim WH, Kushto GP, Kim H, Kafafi ZH. Effect of annealing on the electrical properties and morphology of a conducting polymer used as an anode in organic light-emitting devices. Journal of Polymer Science Part B: Polymer Physics. 2003 Nov 1;41(21):2522-8.
6. Yang XH, Jaiser F, Stiller B, Neher D, Galbrecht F, Scherf U. Efficient polymer electrophosphorescent devices with interfacial layers. Advanced Functional Materials. 2006 Oct 20;16(16):2156-62.
7. Kim YK, Shin MJ, Kim HJ. Annealing temperature effect of hole-collecting polymeric nanolayer in polymer solar cells. Macromolecular Research. 2008 Apr;16(3):185-8.
8. Aasmundtveit KE, Samuelsen EJ, Pettersson LA, Inganäs O, Johansson T, Feidenhans RJ. Structure of thin films of poly (3, 4-ethylenedioxythiophene). Synthetic Metals. 1999 May 1;101(1-3):561-4.

9. Kim Y, Ballantyne AM, Nelson J, Bradley DD. Effects of thickness and thermal annealing of the PEDOT: PSS layer on the performance of polymer solar cells. Organic Electronics. 2009 Feb 1;10(1):205-9.
10. Nguyen TP, Le Rendu P, Long PD, De Vos SA. Chemical and thermal treatment of PEDOT: PSS thin films for use in organic light emitting diodes. Surface and Coatings Technology. 2004 Mar 1;180:646-9.
11. Aernouts T, Geens W, Poortmans J, Heremans P, Borghs S, Mertens R. Extraction of bulk and contact components of the series resistance in organic bulk donor-acceptor-heterojunctions. Thin Solid Films. 2002 Feb 1;403:297-301.
12. Alemu D, Wei HY, Ho KC, Chu CW. Highly conductive PEDOT: PSS electrode by simple film treatment with methanol for ITO-free polymer solar cells. Energy & environmental science. 2012;5(11):9662-71.
13. Nardes AM, Kemerink M, De Kok MM, Vinken E, Maturova K, Janssen RA. Conductivity, work function, and environmental stability of PEDOT: PSS thin films treated with sorbitol. Organic electronics. 2008 Oct 1;9(5):727-34.
14. El-Korashy A, El-Zahed H, Radwan M. Optical studies of [N (CH3) 4] 2CoCl4, [N (CH_3) 4] 2MnCl4 single crystals in the normal paraelectric phase. Physica B: Condensed Matter. 2003 Jun 1;334(1-2):75-81.
15. Li W, Yang R, Wang D. CdTe solar cell performance under high-intensity light irradiance. Solar energy materials and solar cells. 2014 Apr 1;123:249-54.

