Improvement of organic solar cells by flexible substrate and ITO surface treatments

Yuang-Tung Cheng[a], Jyh-Jier Ho[a,*], Chien-Kun Wang[a], William Lee[b], Chih-Chiang Lu[b], Bao-Shun Yau[b], Jhen-Liang Nain[a], Shun-Hsyung Chang[a], Chiu-Cheng Chang[c], Kang L. Wang[d]

[a] Department of Electrical Engineering, National Taiwan Ocean University, No. 2 Pei-ning Rd., Keelung 20224, Taiwan
[b] Electronics and Optoelectronics Research Laboratories, Industrial Technology Research Institute, No. 195 Chung Hsing Rd., 4 Sec. Chu Tung, Hsin Chu 31061, Taiwan
[c] Risk Management Chair Professor, Asia University, 500, Lioufeng Rd., Wufeng, Taichung 41354, Taiwan
[d] Device Research Lab, Electrical Eng., University of California, LA, CA 90095, USA

ARTICLE INFO

ABSTRACT

In this paper, surface treatments on polyethylene terephthalate with polymeric hard coating (PET-HC) substrates are described. The effect of the contact angle on the treatment is first investigated. It has been observed that detergent is quite effective in removing organic contamination on the flexible PET-HC substrates. Next, using a DC-reactive magnetron sputter, indium tin oxide (ITO) thin films of 90 nm are grown on a substrate treated by detergent. Then, various ITO surface treatments are made for improving the performance of the finally developed organic solar cells with structure Al/P3HT:PCBM/PEDOT:PSS/ITO/PET. It is found that the parameters of the ITO including resistivity, carrier concentration, transmittance, surface morphology, and work function depended on the surface treatments and significantly influence the solar cell performance. With the optimal conditions for detergent treatment on flexible PET substrates, the ITO film with a resistivity of 5.6×10^{-4} Ω cm and average optical transmittance of 84.1% in the visible region are obtained. The optimal ITO surface treated by detergent for 5 min and then by UV ozone for 20 min exhibits the best WF value of 5.22 eV. This improves about 8.30% in the WF compared with that of the untreated ITO film. In the case of optimal treatment with the organic photovoltaic device, meanwhile, 36.6% enhancement in short circuit current density (J_{sc}) and 92.7% enhancement in conversion efficiency (η) over the untreated solar cell are obtained.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Recently, flexible optoelectronic devices such as organic light emitting diodes (OLEDs), smart phones, personal digital assistants (PDAs), touch-panel displays and flexible polymer solar cells have become popular [1–5]. As these flexible solar cells grow, it is essential that indium tin oxide (ITO) as electrode material possess such special properties as excellent electrical conductivity, high transparency [6–8], and good chemical stability in the spectrum [9,10]. Therefore, ITO which has a wide band gap (3.3–4.3 eV) [11,12] and relatively high work function (WF) [13,14] are widely used. In order to evaluate the effects of lightness, thinness and high impact resistance, an ITO is usually sputtered onto a flexible transparent plastic substrate in various sizes and curvilinearly flexible shapes.

In general, polymers, which are transparent when visible, have the advantages of having high mechanical strength such as softness and low density [15]. Thus, the polymer material of polyethylene-terephthalate with polymeric hard coating (PET-HC) is considered as the flexible substrate in this research. This material has been widely used in the electrical and electronics industries due to the excellent dielectric, thermal, chemical and mechanical properties [16]. Moreover, effective surface treatments of a flexible PET-HC substrate enable us to make mechanically stable ITO electrode with good robustness, due to an improved adhesion between the ITO and the flexible PET-HC substrate. In addition, the treated ITO on a flexible PET-HC substrate will enhance the effective extraction of hole carriers from active organic layers [11].

If an ITO is deposited on an untreated substrate, the associated organic solar cell usually exhibits poor performance [17,18]. The surface properties of polymers with organic materials often do not satisfy the demands for wettability and adhesion etc. [19,20]. Additionally, the surface of ITOs on flexible PET-HC substrates cannot create new bonds with other atoms and thus can cause a decrease in the WF [4]. Since the WF of ITOs affects the efficiency of carrier injection into organic layers, it is important to investigate the relationships between cleaning methods and surface properties. Numerous researchers [21–23] have investigated into methods on how to improve the WF of ITO surface. The well known

methods of surface treatment used to develop polymer substrate include plasma treatment [24,25], flame treatment [26] and chemical treatment [17,27–29]. Most of the previous works indicate that an increasing WF of an ITO surface reduces the energy barrier at ITO/polymer interface decreased with increasing WF of ITO. This fact creates certain good properties such as better adhesion. The interfacial adhesion between a polymeric layer and an ITO plays an important role in improving the photovoltaic (PV) performance. Because organic solar cells are thin-film devices, contamination on the surface must be avoided. A small amount of contamination on the surface can greatly alter the WF, or the interfacial barrier height between the polymer and the ITO. In this work, substrates and ITOs are cleaned respectively by detergent, ultraviolet (UV) ozone, and its combination (i.e., D&U stands for detergent and then UV ozone treatment) to eliminate surface pollutants and alter the chemical composition for improving their applications.

The correlation between the WF and the chemical composition on an ITO surface cleaned by various methods using UV/visible/near-infrared spectrometer and photoelectric detector is examined. Among all surface treatments, D&U treatment is the most effective technique to increase the WF of ITO. It is proposed that D&U is most effective in removing organic contamination from the substrate and surface of ITO thin film. In this study, the electrical and optical properties of an ITO thin film deposited on a flexible PET-HC substrate at room temperature by DC magnetron sputter are investigated. Currently, ITO development focuses on optimizing charge injection and transport at low cost [13]. A change in ITO WF will alter the charge carrier injection barrier at ITO/organic interface.

The PEDOT:PSS (poly(3,4-ethylenedioxythiophene))-poly(styrenesulfonate)) and the photoactive layer P3HT:PCBM (poly-(3-hexthiophene))-([6,6]-phenyl-C_{61}-butyric acid methyl ester) are prepared by simple spin-coating route. Polymer solar cells have been prepared using the approved layer setup Al/P3HT:PCBM/PEDOT:PSS/ITO/PET. The PV effects on developed solar cells have been characterized in previous work [30]. In the meantime, the effect of ITO surface treatments on the performance of the developed organic solar cell is investigated [31,32]. It is found that the ITO surface treatment obviously affects the short-circuit current density (J_{sc}) in organic solar cells and that there is no relationship between open-circuit voltage (V_{oc}) and ITO surface treatments. Besides, the electrical, optical, structural, mechanical, and the surface properties of ITO grown on a flexible PET-HC substrate using a simple spin-coating system for organic solar cells are investigated. Accordingly, the optimal results can be obtained from an efficient PV that can constitute every type of plastic optoelectronic devices and related products.

2. Experiments

The flexible substrates used in this series of experiments are PET with a polymeric hard coating (Kimoto Tech, Inc., denoted PET-HC), whose surfaces are developed to ensure that repeated use does not produce surface scarring. The thickness of substrate is 125 μm, and the transmittance is 91% throughout the visible spectrum. The flexible PET-HC substrates are cut into pieces approximately 5 cm × 5 cm size, taken from the manufacturer without any pre-treatment, different cleaning processes are used to remove the contaminations on the flexible PET-HC substrate surface. In this research, the flexible PET-HC substrates are cleaned by detergent and UV ozone. In order to study the effect of surface wetting properties of PET-HC on the device performance, each sample contact angle is measured for the inspection of its surface cleanliness.

After cleaning and mounting the DC-reactive magnetron sputter is applied to deposit an ITO on a flexible PET-HC substrate at room

temperature. The target consists of In_2O_3 and SnO_2 at a weight proportion of 9:1, which is placed at a distance of 60 mm from a flexible PET-HC substrate. The sputtering power input to a target is adjusted to 50 W. The total working pressure of 4×10^{-6} Torr consists of a gas mixture of argon (Ar) and oxygen (O_2). While the flow rate of O_2 gas is maintained at a fixed value of 1 sccm, the Ar flow rate is adjusted in the range of 20–60 sccm during different film growth stages due to different substrate treatments. The thickness of ITO thin film is approximately 90 nm and the temperature is grown at room temperature during the whole processes.

In order to compare among different ITO surface treatments, the substrates treated with different manners are placed on a sample holder and all the solar cells are fabricated during the same deposition process. The X-ray diffraction (XRD, Siemens D5000 with Cu Kα radiation) is adjusted to the 2θ mode and scanning electron microscopy (SEM, Hitachi Field-Emission S-4800) is used to characterize the crystal structure. Transmittance and reflectance of the ITO layer are measured by a Shimadzu MPC-3100 UV/VIS/NIR spectrometer within a wavelength range from 400 to 700 nm. The WF and the visible light transmittance of the deposited ITO film are measured by a photoelectron spectrometer (Riken-Keiki, AC-2) and spectrophotometer (Hitachi, U4001) respectively. The sheet resistance of the sample is measured by a 4-point probe (Veeco, FPP-50000), and the resistivity of the film was calculated. Carrier concentration and mobility are obtained from Hall-effect measurement (Keithley 2420) at room temperature.

The schematic device structure of the proposed solar cell is illustrated in Fig. 1. The proposed structure consists of P3HT:PCBM/PEDOT:PSS layers which are inserted between the cathode Al and the anode ITO substrate. The procedure for fabricating a solar cell is described as follows: the substrate is cleaned by detergent, and ITO surface is treated by different manners. After
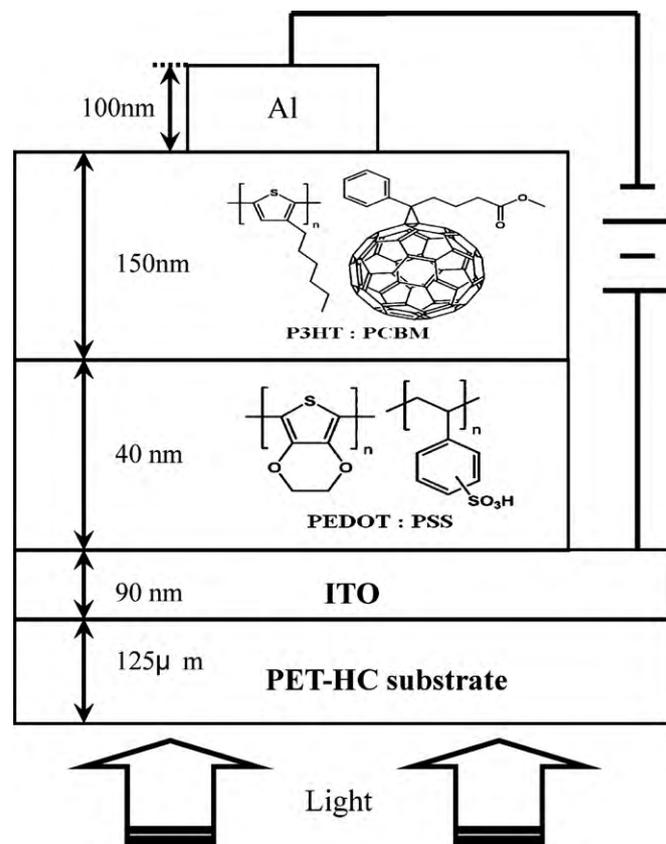

Fig. 1. Schematic configuration of plastic solar cell in Al/P3HT:PCBM/PEDOT:PSS/ITO/PET-HC structure.
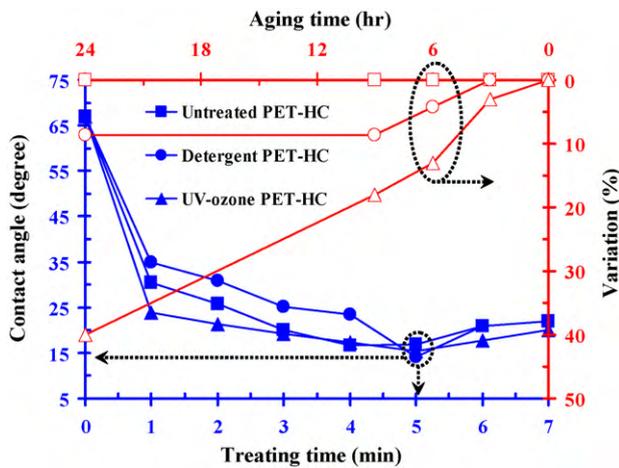
Fig. 2. The profile curves of different treatment manners (■: untreated; ●: detergent; ▲: UV ozone) on the corresponding contact angles (in degree) with treating time (on bottom-left axis), and the corresponding variation (in %) with aging time (on top-right axis) respectively, all on the PET-HC substrate.
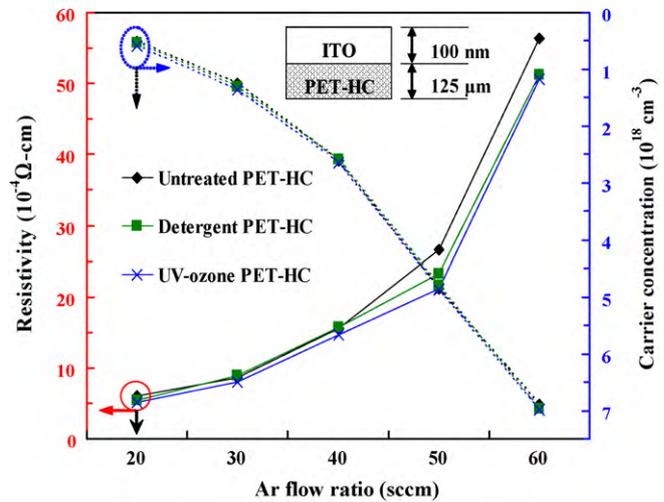

Fig. 3. The variations of the resistivity and the carrier concentration of the argon flow rate during the deposition of ITO thin film on the treated PET-HC substrate at room temperature.

substrate is cleaned, buffer layer (PEDOT:PSS) in the solar cell structure is spin-coated at 4000 rpm for 30 s on the ITO surface. The thickness of the dried PEDOT:PSS layer is about 40 nm. After the buffer layer is formed, the device is transferred into a nitrogen-filled glove box for coating a photoactive layer. The photoactive layer is a mixed solution of P3HT and PCBM which are then dissolved in 1,2-dichlorobenzene (DCB) in the concentration of 16 mg/ml separately. The solution for photoactive layer is achieved by mixing P3HT and PCBM solution in the ratio 1:1 and then heated to 80 °C for 1 h. The photoactive layer is then spin-coated on the buffer layer at 600 rpm for 60 s and naturally dried in the glove box. The thickness of the photoactive layer is about 150 nm. Al cathode is then deposited by evaporation through a shadow mask to the thickness of 100 nm. Organic solar cells have been prepared using the approved layer setup Al/P3HT:PCBM/PEDOT:PSS/ITO/PET-HC. For simplification of terrestrial solar-cell characterization, the induced current density–voltage (J–V) curves of the developed devices are measured under the air mass (AM1.5G) of the solar simulator (Wacom, Model: WXS-220S-L2) at 1000 W/m^2 irradiation power.

3. Results and discussion

Measuring the contact angle is a useful technique to determine the free energy of a surface [33]. The substrate treated by various manners to inspect each sample's surface cleanliness is measured. Fig. 2 (bottom-left axes) shows the treating time variation of a contact angle for flexible PET-HC substrates treated by detergent and UV ozone. The contact angle of the untreated substrate is about 67°. For these two treatment methods, the lowest contact angles are achieved at 5 min treating time. These optimal results are attributed to the surfaces of substrates reacting rapidly to residual carbon molecules that can enlarge contact angle. After having been treated by different manners, carbon contamination is significantly reduced [14].

The aging deterioration of different treatments is also investigated (top-right of Fig. 2), while each sample is exposed to atmosphere for 0, 3, 6, 9, and 24 h, respectively. In the case of the flexible PET-HC substrate, the contact angle slightly varies within the first 6 h. After 9 h aging time, the detergent treatment holds constant with stable contact angles, and the curve of UV-ozone treatment varies greatly with oxygen damage on the substrate surface. This phenomenon is agreed with previous researches [34], resulting from continuous chemical reactions from the remaining active radicals on the PET-HC surface with O$_2$ or moisture in ambi-

ent air, or from free rotation of the O$_2$-containing hydrophilic polar groups into the inside of PET-HC. Obviously, the detergent treatment produces the lowest contact angle (14.1°) at 5 min treating time, and slightly varies within 24 h aging duration.

The ITO films are deposited on flexible PET-HC substrates differed by untreated, detergent, and UV-ozone treatment, separately. Fig. 3 shows that both resistivity and carrier concentration is a function of Ar flow rate when ITO thin films are deposited on the flexible PET-HC substrate at room temperature. It is clear that the resistivity and carrier concentration of the ITO films dramatically changes with the rate of Ar. The resistivity of the ITO grown at flow ratio 20:1 (Ar:O$_2$) is lower than that at higher flow ratio 30:1 (Ar:O$_2$). However, flow ratio 20:1 (Ar:O$_2$) results in an abrupt increase of the carrier concentration. We conclude that increasing Ar flow rate enhances carrier concentration and decreases Hall mobility due to the dissipation of oxygen vacancies. The optimal condition of flow ratio (Ar:O$_2$) at 20:1 for growing an ITO film can get the lowest resistivity. The reason is the enhanced carrier mobility resulting from the dissipation of oxygen vacancy. The optimized growth conditions of flow ratio (Ar:O$_2$), DC sputter power, working pressure, and deposition time are 20:1, 50 W, 4×10^{-6} Torr, and 20 min, respectively. Meanwhile, the high quality thin film with resistivity as low as 5.6×10^{-4} Ω cm and carrier concentration as 0.535 × 10^{18} cm^{-3} can be obtained by controlling the Ar:O$_2$ flow ratio on the substrate with detergent treatment.

Fig. 4 depicts the total visible transmittance spectra (400–700 nm) of ITO thin films deposited by a DC-reactive magnetron sputter at room temperature on the flexible PET-HC substrates by detergent and UV-ozone treatments, respectively. The transmittance spectrum of an untreated substrate is presented for comparison. All ITO films' thicknesses are about 90 ± 5% nm. It is significant that transmittances of ITO films reach the saturation stage (>80%) in the 470–600 nm range which is much higher than that in the 400–460 nm region [35]. The sharp absorption edges in the transmittance spectra are caused by an extrinsic band gap of ITO film in the range of 3.3–4.3 eV [11,12]. The best value of average transmittance (in the insert of Fig. 4) is 84.10% treated by the detergent method. However, all of the average transmittance within visible range of a treated PET-HC substrate is higher than 83%, which is usable for optoelectronic applications [36].

Fig. 5 shows the typical 2θ mode XRD spectra of ITO films grown on substrates treated by different manners. For comparison, the XRD spectrum of ITO film deposited on an untreated flexible
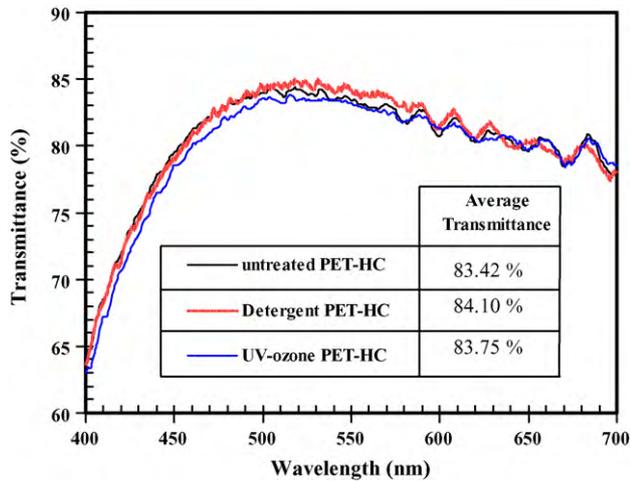
Fig. 4. The transmittance spectra of ITO films on substrates treated by detergent and UV-ozone treatments, respectively. The average values of all transmittance spectra in the visible range are also included.

Fig. 5. The XRD patterns of ITO films deposition on substrates treated by different manners.

PET-HC substrate is also shown where no significant diffraction peak may be observed indicating an amorphous structure within the untreated flexible PET-HC substrate. However, the ITO film deposited on substrate surface treated by detergent and UV ozone are polycrystalline. The diffraction peaks at 2θ correspond to diffractions of In_2O_3 cubic crystalline structure ($30.51°$, $35.38°$, $50.9°$, and $61.51°$ correspond respectively to $(2\,2\,2)$, $(4\,0\,0)$, $(4\,4\,0)$, and $(6\,2\,2)$) [36]. This indicates that the degree of crystalline of the substrate surface treated by detergent is higher than that of the untreated substrate surface. The residual carbon and the contaminants can be removed by the detergent and UV ozone treatments [14].

Fig. 6 shows the SEM morphologies of an ITO deposited on substrates by different treatments. Compared with the untreated image in Fig. 6(a), the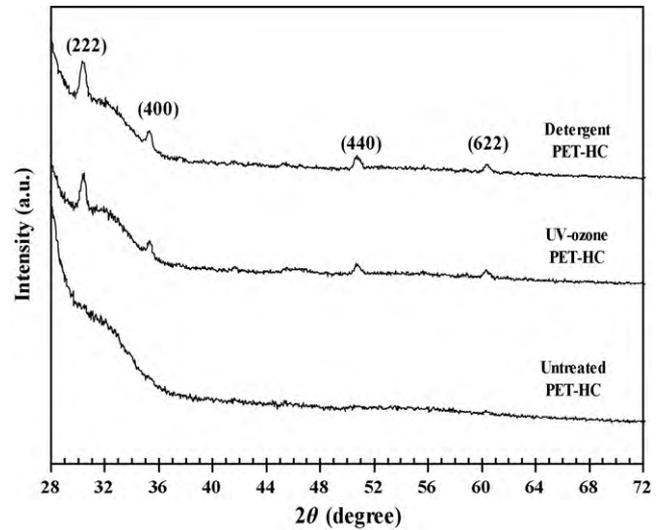 morphology of the ITO film (as shown in Fig. 6(b)) deposited on the 5 min detergent treatment substrate does not significantly vary, thus dispersing the surface spherical particles and showing the flat surface with low roughness. Further, there is no defect such as pinholes, cracks on the ITO films treated by detergent treatment. Moreover, Fig. 6(c) with 5 min UV ozone treatment shows a flat ITO without a pinhole. Fig. 6(d) shows high-resolution cross-sectional SEM images of an 89 nm ITO film. The substrate is treated by detergent manner. No defects are found on the coatings, and the surface is smooth on this length scale. From Figs. 2, 5 and 6 discussed above, the optimal surface condition is 5 min detergent treatment on a flexible PET-HC substrate. For those ITO films as-deposited on the treated substrate, it is confirmed that we need to make surface treatment, thus determining the optimum process parameters for solar-cell applications.
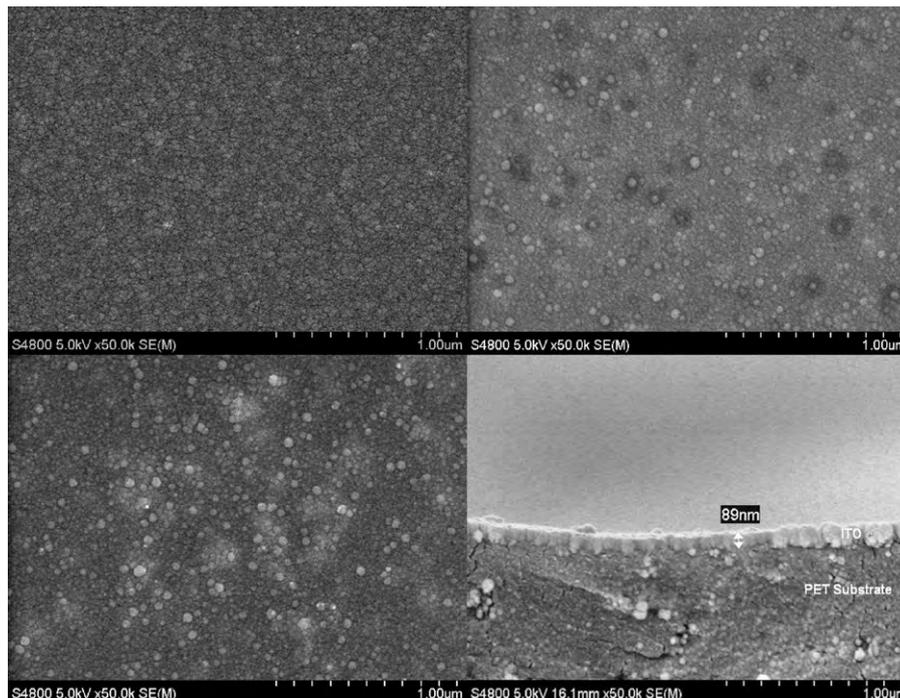

Fig. 6. The SEM images of ITO films are deposited on the flexible PET-HC substrate by (a) untreated, (b) 5 min detergent, and (c) 5 min UV ozone treatments, respectively. (d) Cross-section image of as-deposited ITO film with thickness of 89 nm for 5 min detergent treatment.
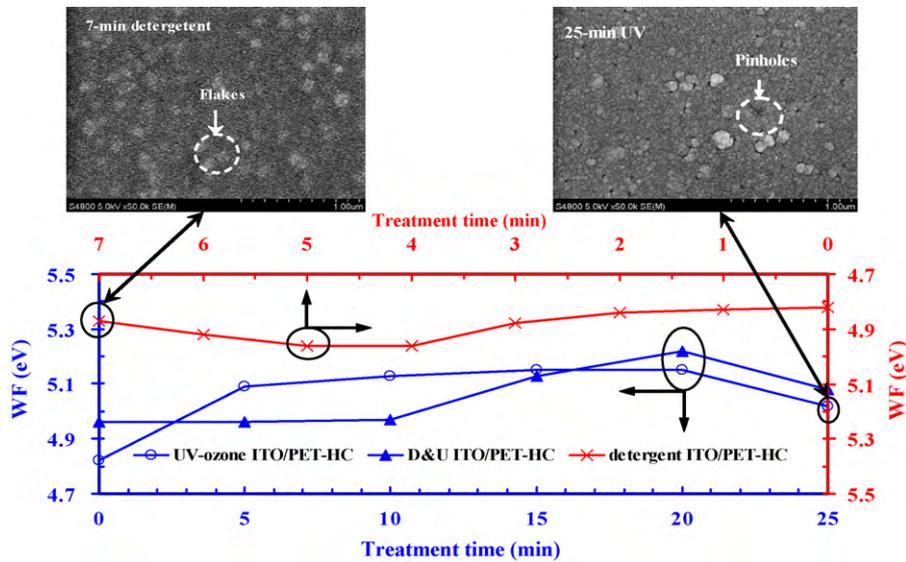
Fig. 7. The WF variation (in eV) is plotted as a function of the surface treatment time (in min) on the ITO/PET-HC substrate. In which, the ITO films are treated by detergent, and then treated by detergent, UV-ozone, and detergent plus UV-ozone (D&U) treatments, separately. The damage-SEM images treated by 7-min detergent (left), and 25-min UV ozone (right) are also included.

The WF properties of ITO surface treated by different manners are analyzed by a photoelectron spectrometer. Fig. 7 shows that WF is a function of two variables, i.e., treatments and treatment time. In which, the highest WF values 4.96 eV and 5.15 eV treated by 5 min detergent and 20 min UV ozone methods can be obtained respectively. However, the D&U-treatment as 5 min detergent plus 20 min UV-ozone treatment as shown in Fig. 7 is defined in this research. Obviously, the optimal WF value of 5.22 eV by D&U treatment can be achieved. This improves about 8.30% in the WF compared with that of the untreated (4.82 eV, as-deposited) ITO film. The inserted SEM images illustrate extreme conditions of 7 min detergent and 25 min UV ozone treatment that generates defect such as flakes peeled (left photo) and pinholes punched (right photo) on the ITO surface. This clearly shows that the increase of WF is closely related to the oxidative degree (created during the UV-irradiation) on the ITO surface. This phenomenon is consistent with most of defect states created below the edge of the conduction band pushing the Fermi level to lower values. However, comparing these data with ITO film deposited on substrate treated by detergent, we can conclude that the surface of the ITO films treated by D&U is the best judged from WF value. Finally, D&U is a simple, attractive, and promising technique for the production of ITO thin films on the substrates treated by detergent.

Fig. 8 shows the current density–voltage (J–V) characteristics of the Al/P3HT:PCBM/PEDOT:PSS/ITO/PET-HC device under AM1.5G illumination with intensity of 100 mW/cm^2 at room temperature. All organic solar cells on the substrate treated by detergent shows comparable results. This demonstration indicates the good quality of the photoactive layer on the treated surface. Detailed characteristics of solar cells such as J_{sc}, V_{oc}, fill factor (FF) and efficiency values are also shown in the inset table, respectively. It can be seen that the J_{sc} (in mA/cm^2) of ITO surfaces treated by detergent, UV-ozone, and D&U are 6.7, 8.48, 8.77, respectively. The J_{sc} for ITO surface with D&U treatment increases from 6.42 to 8.77, which is 36.6% enhancement as compared to the untreated organic solar cell. This may result from the differences in the PEDOT:PSS layer or higher shunts caused by the influence of film preparation procedures [37]. Nevertheless, the discrepancy in J_{sc} of the direct comparable (untreated) cells should be a consequence of differences in film morphology resulting from the ever individual preparation procedure. As can be seen in inset table, V_{oc} slightly changes because of

different treating methods. It is found that the V_{oc} of the organic solar cell directly correlates with the acceptor strength, i.e., it is determined by the HOMO-LUMO energy gap of donor and acceptor, respectively [38–41]. As a consequence, the conversion efficiency for ITO surface treated by D&U (2.12%) is higher than ITO surfaces treated by detergent (1.42%) and UV-ozone (1.91%). Moreover, the efficiency increased from 1.1% to 2.12%, which is 92.7% enhancement as compared to the untreated organic solar cell. The larger enhancement for conversion efficiency as compared to J_{sc} results from the increase of the FF. The short circuit current is the parameter showing the highest dependency on the ITO surface treatments. Compared with the untreated solar cell, high J_{sc} is obtained under all three treatments. It could be seen that the carrier collection efficiency and J_{sc} are influenced by the concentration of traps and defects on the ITO surface having connection with the surface treatments [42].

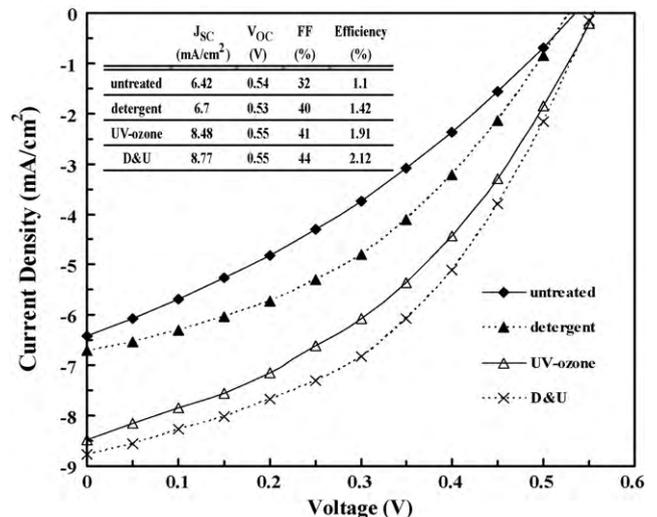|	J_{SC} (mA/cm^2)	V_{OC} (V)	FF (%)	Efficiency (%)
untreated	6.42	0.54	32	1.1
detergent	6.7	0.53	40	1.42
UV-ozone	8.48	0.55	41	1.91
D&U	8.77	0.55	44	2.12

Fig. 8. The current–voltage characteristics of Al/P3HT:PCBM/PEDOT:PSS/ITO/PET-HC structure solar cell with different ITO surface treatments under AM1.5G illumination. The inset table shows the comparison of the solar cells parameters for different ITO surface treatments.

4. Conclusions

The effects on the flexible PET-HC substrates treated by different manners have been investigated as contact angle technique is a known method for assessing the cleanliness of the substrates. The ITO films are deposited at room temperature by DC magnetron sputtering from a ceramic target of a 90% In–10% Sn alloy. It is found that optical properties of the ITO (resistivity and carrier concentration) are critically dependent on the flow ratio of Ar to O_2 during sputtering. Even though the surface of the ITO film is treated by detergent, the ITO film with a resistivity of 5.6×10^{-4} Ω cm and average optical transmittance of 84.1% in the visible-region can be obtained. The cleanliness can also be monitored by complementary XPS. Detergent can significantly enhance the degree of crystalline of organic solar cells. In addition, the ITO film shows morphological structure and a very smooth surface area. In conclusion, the relationship between the methods used to clean ITO surface and the WF using photoelectron spectrometer are investigated. ITO surface cleaned by detergent for 5 min and by UV ozone for 20 min results in significant increase in the WF value (5.22 eV). The optimal surface treatment (detergent for 5 min and UV ozone for 20 min) increases conversion efficiency for Al/P3HT:PCBM/PEDOT:PSS/ITO/PET-HC organic solar cell with conversion efficiency of 2.12% being the best. These results show that polymer-based materials and manufacturing techniques are suitable for flexible solar cells. Using the best treatment, 36.6% enhancement in J_{sc} and 92.7% enhancement in conversion efficiency over the untreated organic solar cell have been demonstrated.

Acknowledgments

References

[1] J.H. Burroughes, D.D.C. Bradley, A.R. Brown, R.N. Marks, K. Mackay, R.H. Friend, P.L. Burns, A.B. Holmes, Light-emitting diodes based on conjugated polymers, Nature 347 (1990) 539–541.
[2] M. Berggren, O. Inganäs, G. Gustafsson, J. Rasmusson, M.R. Andersson, T. Hjertberg, O. Wennerström, Light-emitting diodes with variable colours from polymer blends, Nature 372 (1994) 444–446.
[3] R.H. Friend, R.W. Gymer, A.B. Holmes, J.H. Burroughes, R.N. Marks, C. Taliani, D.D.C. Bradley, D.A. Dos Santos, J.L. Brédas, M. Lögdlund, W.R. Salaneck, Electroluminescence in conjugated polymers, Nature 397 (1999) 121–128.
[4] Z. Zhang, Y. Zhong, C. Liu, S. Yin, W. Zhang, D. Shi, Study on the surface wetting properties of treated indium-tin-oxide anodes for polymer electroluminescent devices, Phys. Stat. Solid A 198 (1) (2003) 197–203.
[5] L.M. Wang, Y.-J. Chen, J.-W. Liao, Characteristics of indium-tin-oxide thin films grown on flexible plastic substrates at room temperature, J. Phys. Chem. Solids 69 (2008) 527–530.
[6] C.G. Granqvist, A. Hultåker, Transparent and conducting ITO films: new developments and applications, Thin Solid Films 411 (2002) 1–5.
[7] J.-J. Ho, C.-Y. Chen, C.-M. Huang, J.L. William, W.-R. Liou, C.-C. Chang, Ion-assisted sputtering deposition of antireflection film coating for flexible liquid-crystal display applications, Appl. Opt. 44 (29) (2005) 6176–6180.
[8] J.-J. Ho, C.-Y. Chen, Power effects in indium-zinc oxide thin films for OLEDs on flexible applications, J. Electrochem. Soc. 152 (1) (2005) G57–G61.
[9] C.J. Bloom, C. Michael Elliott, P.G. Schroeder, C. Brian France, B.A. Parkinson, Low work function reduced metal complexes as cathodes in organic electroluminescent devices, J. Phys. Chem. B 107 (2003) 2933–2938.
[10] C.W. Tang, S.A. VanSlyke, Organic electroluminescent diodes, Appl. Phys. Lett. 51 (12) (1987) 913–915.
[11] G.Y. Kim, J.S. Oh, E.H. Choi, G.S. Cho, S.O. Kang, J. Cho, Work function change on O-plasma treated indium-tin-oxide, Mater. Sci. Eng. B 100 (2003) 275–279.
[12] L.H. Nguyen, S. Günes, H. Neugebauer, N.S. Sariciftci, F. Banishoeib, A. Henckens, T. Cleij, L. Lutsen, D. Vanderzande, Low bandgap poly (thienylene vinylene) for organic solar cells: photophysics and photovoltaic performance, Proc. SPIE 61921T (2006) 1–7.
[13] J.-J. Ho, C.-Y. Chen, R.Y. Hsiao, O.L. Ho, The work function improvement on indium-tin-oxide epitaxial layers by doping treatment for organic light-emitting device applications, J. Phys. Chem. C 111 (23) (2007) 8372–8376.
[14] C.N. Li, C.Y. Kwong, A.B. Djurišić, P.T. Lai, P.C. Chui, W.K. Chan, S.Y. Liu, Improved performance of OLEDs with ITO surface treatments, Thin Solid Films 477 (2005) 57–62.
[15] N. Lobstein, E. Millon, A. Hachimi, J.F. Muller, M. Alnot, J.J. Ehrhardt, Deposition by laser ablation and characterization of titanium dioxide films on polyethylene-terephthalate, Appl. Surf. Sci. 89 (1995) 307–321.
[16] R. Morent, N. De Geyter, C. Leys, L. Gengembre, E. Payen, Study of the ageing behaviour of polymer films treated with a dielectric barrier discharge in air, helium and argon at medium pressure, Surf. Coat. Technol. 201 (2007) 7847–7854.
[17] B.L. Low, F.R. Zhu, K.R. Zhang, S.J. Chua, An in situ sheet resistance study of oxidative-treated indium tin oxide substrates for organic light emitting display applications, Thin Solid Films 417 (2002) 116–119.
[18] K. Sugiyama, H. Ishii, Y. Ouchi, K. Seki, Dependence of indium-tin-oxide work function on surface cleaning method as studied by ultraviolet and X-ray photoemission spectroscopies, J. Appl. Phys. 87 (1) (2000) 295–298.
[19] D.B. Kim, J.K. Rhee, S.Y. Moon, W. Choe, Feasibility study of material surface modification by millimeter size plasmas produced in a pin to plane electrode configuration, Thin Solid Films 515 (2007) 4913–4917.
[20] F. Rupp, L. Scheideler, J. Geis-Gerstorfer, Effect of heterogenic surface on contact angle hysteresis: dynamic contact angle analysis in material sciences, Chem. Eng. Technol. 25 (9) (2002) 877–882.
[21] G.M. Wu, H.H. Lin, H.C. Lu, Work function and valence band structure of tin-doped indium oxide thin films for OLEDs, Vacuum 82 (2008) 1371–1374.
[22] S.-H. Chen, Work-function changes of treated indium-tin-oxide films for organic light-emitting diodes investigated using scanning surface-potential microscopy, J. Appl. Phys. 97 (073713) (2005) 1–4.
[23] V.C. Hoven, R. Yang, A. Garcia, V. Crockett, A.J. Heeger, G.C. Bazan, T.-Q. Nguyen, Electron injection into organic semiconductor devices from high work function cathodes, PNAS 105 (35) (2008) 12730–12735.
[24] Z. Ziari, A. Bellel, S. Sahli, Y. Segui, P. Raynaud, A comparative study on the effect of VUV radiation in plasma SiOx-coated polyimide and polypropylene films, Prog. Org. Coat. 61 (2008) 326–332.
[25] A. Bellel, S. Sahli, Z. Ziari, P. Raynaud, Y. Segui, D. Escaich, Wettability of polypropylene films coated with SiOx plasma deposited layers, Surf. Coat. Technol. 201 (2006) 129–135.
[26] D. Satas, A.A. Tracton, Coating Technology Handbook, 2nd ed., Marcel Dekker, New York, 2001.
[27] L.M. Mottern, F. Tyholdt, A. Ulyashin, A.T.J. van Helvoort, H. Verweij, R. Bredesen, Textured indium tin oxide thin films by chemical solution deposition and rapid thermal processing, Thin Solid Films 515 (2007) 3918–3926.
[28] G. Wantz, L. Hirsch, N. Huby, L. Vignau, J.F. Silvain, A.S. Barriére, J.P. Parneix, Correlation between the indium tin oxide morphology and the performances of polymer light-emitting diodes, Thin Solid Films 485 (2005) 247–251.
[29] H. Tomonaga, T. Morimoto, Indium-tin-oxide coatings via chemical solution deposition, Thin Solid Films 392 (2001) 243–248.
[30] Y.-T. Cheng, J.-J. Ho, W.J. Lee, S.-Y. Tsai, Y.-A. Lu, J.-J. Liou, S.-H. Chang, K.L. Wang, Int. J. Photoenergy 2010 (2010) 1–6.
[31] G.-M. Ng, E.L. Kietzke, T. Kietzke, L.-W. Tan, P.-K. Liew, F. Zhu, Optical enhancement in semitransparent polymer photovoltaic cells, Appl. Phys. Lett. 90 (103505) (2007) 1–3.
[32] Y. Zhou, F. Li, S. Barrau, W. Tian, O. Inganäs, F. Zhang, Inverted and transparent polymer solar cells prepared with vacuum-free processing, Solar Energy Mater. Solar Cells 93 (2009) 497–500.
[33] K.-X. Ma, C.-H. Ho, F. Zhu, T.-S. Chung, Investigation of surface energy for organic light emitting polymers and indium tin oxide, Thin Solid Films 371 (2000) 140–147.
[34] M.E. Roberts, M.C. LeMieux, A.N. Sokolov, Z. Bao, Self-sorted nanotube networks on polymer dielectrics for low-voltage thin-film transistors, Nano Lett. 9 (7) (2009) 2526–2531.
[35] H. Neugebauer, Concepts and strategies for photovoltaic devices with fullerenes, Electrochem. Soc. Proc. 12 (2002) 19–21.
[36] L. Hao, X. Diao, H. Xu, B. Gu, T. Wang, Thickness dependence of structural, electrical and optical properties of indium tin oxide (ITO) films deposited on PET substrates, Appl. Surf. Sci. 254 (2008) 3504–3508.
[37] K. Petrisch, PhD Thesis, Technische Universität Graz, Austria, 2000.
[38] C.-T. Lee, Q.-X. Yu, B.-T. Tang, H.-Y. Lee, Effects of plasma treatment on the electrical and optical properties of indium tin oxide films fabricated by r.f. reactive sputtering, Thin Solid Films 386 (2001) 105–110.
[39] F. Brovelli, B.L. Rivas, J.C. Bernède, M.A. del Valle, F.R. Díaz, Y. Berredjem, Electrochemical and optical studies of 1,4-diaminoanthraquinone for solar cell applications, Polym. Bull. 58 (2007) 521–527.
[40] S. Garabagiu, G. Mihailescu, Gold nanoparticles bind to porphyrins: a potential dye-sensitized solar cell, J. Phys.: Conf. Ser. 182 (012048) (2009) 1–4.
[41] M. Al-Ibrahim, S. Sensfuss, J. Uziel, G. Ecke, O. Ambacher, Comparison of normal and inverse poly (3-hexylthiophene)/fullerene solar cell architectures, Solar Energy Mater. Solar Cells 85 (2005) 277–283.
[42] C.Y. Kwong, A.B. Djurišič, P.C. Chui, L.M.S. Lam, W.K. Chan, Improvement of the efficiency of phthalocyanine organic Schottky solar cells with ITO electrode treatment, Appl. Phys. A 77 (2003) 555–560.