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ITO Etched by Photolithography Used in the Fabrication of Flexible Organic Solar Cells with PET Substrates

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Abstract: In this study, the authors have shown the power conversion efficiency of flexible organic solar cells. The structure of the device is PET/ITO/PEDOT: PSS/P3HT: PCBM/Al. P3HT (poly-3-hexylthiophene). It was used as an electron donor, PCBM ([6, 6]-phenyl C61-butyric acid methyl ester) as an electron acceptor and PEDOT: PSS used as a HIL (hole injection layer). These materials were deposited by spin coating method on the flexible substrates. Photolithography method is used to etch ITO. The electrical parameters of the fabricated cells were investigated by means of *J* (V), *FF* (fill factor), the efficiency (η), photocurrent and IPCE measurement. It was observed that 45% of the absorbed photons are converted into current. The results obtained using etching technology by photolithography is better than that obtained in the clean room.

Key words: Flexible substrate, PET, photolithography, organic solar cells, P3HT: PCBM.

1. Introduction

Organic optoelectronic devices have been object of intense research in the last years, based on advantages as the possibility of producing large areas devices and the possibility to change the optoelectronic features of these materials without considerable changes in the process production [1].

PV (photovoltaic) cells are more and more attractive as clean renewable energy source and their lower fabrication cost and possibility of using flexible substrates [2]. To create an efficient PSC (polymer solar cell), it is necessary to optimize electricity generation, dissociation and carrier transport. The flexible solar cells fabricated using the roll-to-roll technology exhibited a power conversion efficiency of 1.88% [3].

Multilayer structure CIC (conductor-insulator-conductor) anode structure increases the photocurrent of the cells [4].

The argon ion treatments of the PET (polyethylene terephthalate) substrate improve the flexibility of the ITO (indium tin oxide) electrode [5]. The parameters of ITO such as resistivity, carrier concentration, transmittance, surface morphology and work function depend on the surface treatments and significantly influence the performances of the solar cells [6]. The internal quantum efficiency of a solar cell depends on its intrinsic material properties, such as its cristallinity, energy band gap, carrier transport behavior and the number of defects and impurities [7]. Thermal annealing improves photocurrent as well as interface between organic layers and metal electrodes due to the reduction of interface defects [8].

Several techniques are used to deposit the polymer layers onto flexible or glass substrates. Such as spin coating, doctor blading, printing, bruch painting, roll-to-roll-technology [8, 9] and rotogravure printing [10].

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TCO (transparent conductive oxides) are widely used in thin film optoelectronic devices. Different classical TCO, such as doped SnO_2 or ZnO, are used in organic solar cells, however they have poor hole exchange with organic material. For many organic electronic devices, thin buffer interlayer is usually inserted between the organic material and the TCO anode to enhance hole exchange at the interface [11, 12].

Flexible tandem solar cells with PES (poly ether sulfones) substrate showed the same efficiency with device on glass substrate [13].

In the present work, the authors presented the etching technology by photolithography for the plastic substrate (PET/ITO). The authors investigate the performances of flexible organic photovoltaic cells of P3HT (poly-3-hexylthiophene): PCBM ([6, 6]-phenyl C61-butyric acid methyl ester) based BHJ (bulk heterojunction) solar cells with Al cathode and ITO/PET as flexible substrates. The parameters of the organic solar cells PET/ITO/P3HT: PCBM/Al and Glass/ITO/P3HT: PCBM/Al such as current density *J* (V), open circuit voltage V_{OC}, *FF* (fill factor), and the photocurrent are presented.

2. Experiment

2.1 ITO Etched by Photolithography

For samples that we used in the production of our cells, we introduced the resin S 1828 on ITO at a speed of 5,000 rpm/min, acceleration of 6,000 rpm/s² during 60 s. The samples were deposited in HCL heated at 90 °C for 2 min. Then cleaned with water, after that the substrates are immersed in the developer to remove the resin. Finally, substrates are immersed in isopropanol. Fig. 1 shows UV dispositive used for hardened the resin.

Fig. 1 UV dispositive used for hardened the resin.

2.2 Fabrication of the Cells

The structure of fabricated flexible organic solar cells used in this study is PET/ITO/PEDOT: PSS/P3HT: PCBM/Al. the photo absorption layer of P3HT: PCBM was deposited by spin coating on the ITO flexible plastic substrates. The ITO was etched with photolithography method as explained in the previous section.

The PET substrate was cleaned for 30 min using the UV-Ozone cleaner.

The PEDOT: PSS (polyethylene dioxythiophene: polysterene sulfonate) used as a HIL (hole injection layer) was then deposited using the spin coating method.

The photo absorption layer of P3HT: PCBM was prepared by dissolving in 1.5 mL of CLB (chlorobenzen) 50 mg of P3HT and 50 mg of PCBM.

Thin layer of aluminum Al (80 nm) used as cathode was evaporated under high vacuum conditions of 3.2×10^{-6} m bar.

The fabricated cells were annealed in the glove box at 110 °C for 30 min.

2.3 Schematic Structure of the Flexible Organic Solar Cell

The schematic device structure of the flexible organic solar cells realized is illustrated in Fig. 2.

3. Results and Discussions

3.1 The Performances of the Flexible Cells

The efficiency of a solar cell is calculated from:

$$\eta = \frac{V_{OC} \cdot I_{SC} \cdot FF}{I_{light}} \quad (1)$$

V_{OC} is the open circuit voltage (V), I_{SC} is the short circuit current in A/m², *FF* is the fill factor, and I_{light} is the incident solar radiation in W/m².

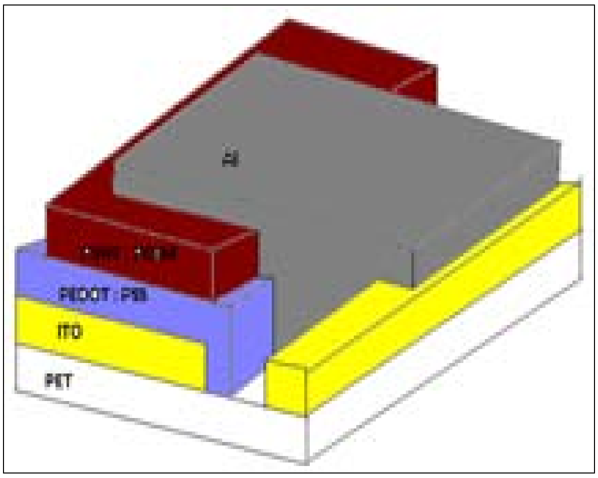

Fig. 2 Schematic configuration of flexible solar cells of PET/ITO/PEDOT: PSS/P3HT: PCBM/Al.

Tables 1 and 2 give comparisons of the characteristics of the cells when the ITO used is etched in the clean room and when the ITO used is etched by photolithography method**.**

3.2 Comparison between Cells with Glass/ITO Substrate and PET/ITO Substrate

Fig. 3 shows the characteristics *J* (V) of solar cells with flexible (PET) substrate and glass substrate. The current density (*J*) as function of voltage (V) was measured in the glove box by illuminating the organic solar cells with AM 1.5 G simulated sunlight with intensity of 100 m·W/cm^2. The difference in the performances of cells is attributed to a decrease in current. The transparency of glass substrate is slightly higher than transparency of flexible PET substrate. So the photocurrent generated is limited by the transparency of the substrate.

Fig. 3 shows *J* (V) characteristics of the cells under illumination.

4. IPCE Measurement of Flexible Organic Solar Cells

4.1 J (V) Characteristics

In this case, the solution of P3HT: PCBM concentration used is (50: 40) mg/mL. The *J* (V) characteristics in the dark (J_{obs}) and under illumination (J_{ilum}) are shown in Fig. 4.

Table 1 Device performances of the flexible organic solar cells.

Cells	V_{OC} (V)	J_{sc} (mA·cm^{-2})	*FF* (%)	η (%)
ITO etched in the clean-room	0.521	6.63	42.1	1.46
ITO etched by photolithography	0.549	7.97	41.9	1.84

V_{OC}—Open circuit voltage, J_{sc}—Short current density, *FF*—Fill factor, η—Efficiency.

Table 2 Shunt and series resistance of the flexible organic solar cells.

Cells	R_{serie} (Ohms)	R_{shunt} (Ohms)
ITO etched in the clean-room	167	1,700
ITO etched by photolithography	157.7	1,699.9

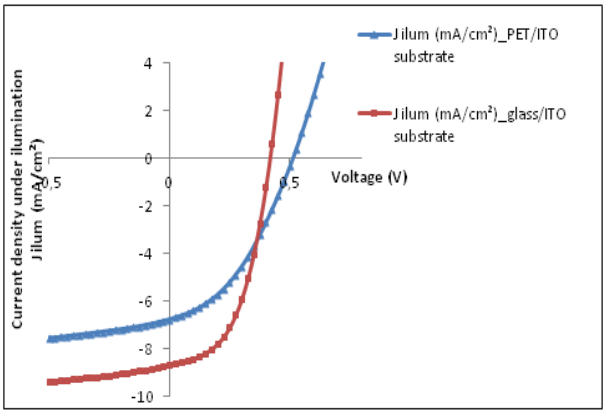

Fig. 3 J_{ilum} (V) characteristics of organic solar cells with PET/ITO substrate and glass/ITO substrate.

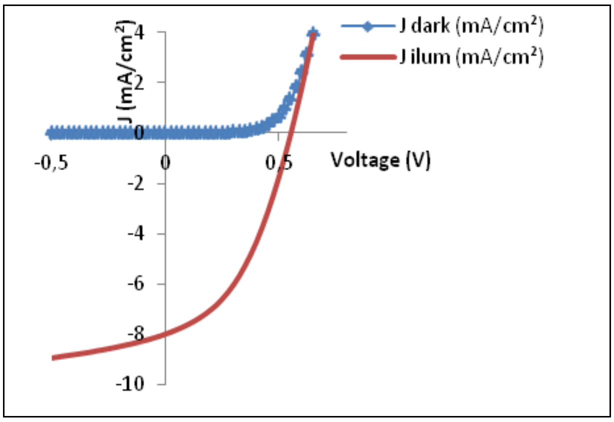

Fig. 4 Current density voltage characteristics (air mass 1.5 G condition with incident light power intensity of 100 m·W/cm^2) of flexible organic solar cell.

4.2 IPCE Measurement

Fig. 5 shows that 45% of the absorbed photons are converted into current. So there is a significant loss outside the active layer. Otherwise an IPCE over to 55% can be expected.

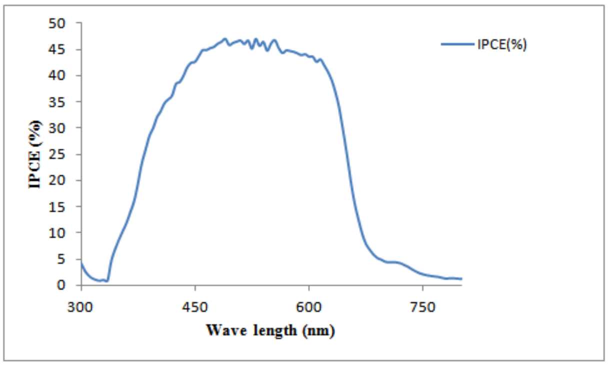

Fig. 5 Power efficiency versus wave length of flexible solar cell (PET/PEDOT: PSS/ITO/P3HT: PCBM/Al).

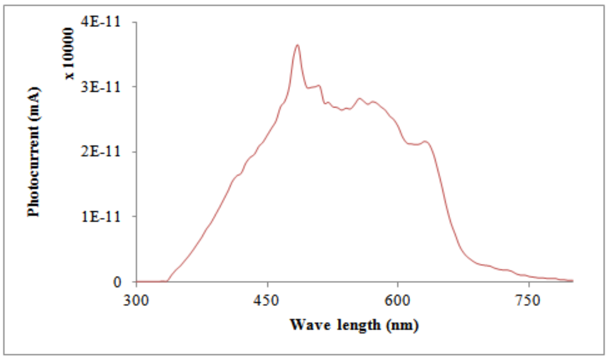

Fig. 6 Photocurrent depending on the wave length of light of a flexible solar cell PET/PEDOT: PSS/ITO/P3HT: PCBM/Al.

4.3 Photocurrent Measurement

Fig. 6 shows photocurrent measurement of a flexible solar cell.

5. Conclusions

Etching technology outside clean room using photolithography is used to fabricate flexible organic photovoltaic cells. The results obtained with photolithography outside clean room are comparable with those obtained in the clean room. In the clean room cell parameters are: V_{OC} = 0.52 V, J_{SC} = 7.97 mA/cm^2, FF = 41.9% and η = 1.46%.

For cells made by photolithography we obtained better results: V_{OC} = 0.55 V, J_{SC} = 7.97 mA/cm^2, FF = 41.9% and an efficiency η = 1.84%.

Several factors contribute to increase the series resistances when the device is left in ambient conditions such as reduction of mobility, metal corrosion at the contact or changes in the contact barrier and charge space regions.

To improve the performances of flexible organic solar cells, parameters should be optimized such as the deposition parameters of the photolithography method.

We believe that the photolithography technology have good promise and potential to meet the goal of large-scale industrial applications.

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References

[1]. R. Valaski, C.D. Canestraro, L. Micaroni, R.M.Q Mello, L.S. Roman, Organic photovoltaic devices based on polythiophene films electrodeposited on FTO substrates, Solar Energy Materials & Solar Cells 91 (2007) 684-688.

[2]. P.G. Karagiannidis, D. Georgiou, C. Pitsalidis, A. Laskarakis, S. Logothetidis, Evolution of vertical phase separation in P3HT: PCBM thin films induced by thermal annealing, Materials Chemistry and Physics 129 (2011) 1207-1213.

[3]. J.H. Choi, J.A. Jeong, J.W. Kang, D.G. Kim, J.K. Kim, S. Na, et al., Characteristics of flexible indium tin oxide electrode grown by continuous roll-to-roll sputtering process for flexible organic solar cells, Solar Energy Materials & Solar Cells 93 (2009) 1248-1255.

[4]. H.W. Tsai, Z.W. Pei, C.C. Chen, S.J. Cheng, W.S. Hseih, P.W. Li, et al., Anode engineering for photocurrent enhancement in a polymer solar cell and applied on plastique substrate, Solar Energy Materials & Solar Cells 95 (2011) 611-617.

[5]. K.H. Choi, J.A. Jeong, J.W. Kang, D.G. Kim, J.K. Kim, Characteristics of flexible indium tin oxide electrode grown by continuous roll-to-roll sputtering process for flexible organic solar cells, Solar Energy Materials & Solar Cells 93 (2009) 1248-1255.

[6]. Y.T. Cheng, J.J. Hoa, C.K. Wang, W. Lee, C.C. Lu, B.S. Yau, et al., Improvement of organic solar cells by flexible substrate and ITO surface treatments, Applied Surface Science 256 (2010) 7606-7611.

[7]. S.Y. Chuang, C.C. Yu, H.L. Chen, W.F. Su, C.W. Chen, Exploiting optical anisotropy to increase the external quantum efficiency of flexible P3HT: PCBM blend solar

cells at large incident angles, Solar Energy Materials & Solar Cells 95 (2011) 2141-2150.

[8]. S. Kim, S. Ryu, Efficiency of flexible organic solar cells as a function of post-annealing temperatures, Current Applied Physics 10 (2010) 181-184.

[9]. S.W. Heo, K.W. Song, M.H. Choi, T.H. Sung, D.K. Moon, Patternable solution process for fabrication of flexible polymer solar cells using PDMS, Solar Energy Materials & Solar Cells 95 (2011) 3564-3572.

[10]. J.M. Ding, A. Vornbrock, C. Ting, V. Subramanian, Patternable polymer bulk heterojunction photovoltaic cells on plastic by rotogravure printing, Solar Energy Materials & Solar Cells 93 (2009) 459-464.

[11]. E.L. Hanson, J. Guo, N. Koch, J. Schartz, S.L. Bernasek, Advanced surface modification of indium tin oxide for improved charge injection in organic devices, J. Am. Chem. Soc. 127 (2005) 10058-10062.

[12]. H.T. Lu, M. Yokoyama, Plasma preparation on indium tin oxide anode surface for organic light emitting diodes, J. Cryst. Growth 260 (2004) 186-190.

[13]. B.J. Lee, H.J. Kim, W. Jeong, J.J. Kim, A transparent conducting oxide as an efficient middle electrode for flexible organic solar cells, Solar Energy Materials & Solar Cells 94 (2010) 542-546.