Supporting Information

Semitransparent organic solar cells based on PffBT4T-2OD with thick active layer and near neutral colour perception towards window application

Leiping Duan *[a], Haimang Yi [a], Zhimeng Wang [a], Yu Zhang [a], Faiazul Haque [a], Borong Sang [a], Rong Deng [a] and Ashraf Uddin *[a]

AUTHOR ADDRESS

[a] School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, NSW 2052, Australia

Corresponding Author

*E-mail: leiping.duan@unsw.edu.au. (L.D.)

*E-mail: a.uddin@unsw.edu.au. (A.U.)

Calculation of CRI

1. Measure transmission of the semi-transparent solar cell using a Perkin Elmer - Lambda 950 in the wavelength range 370 – 740 nm.
2. Find the color coordinates (x,y) in the CIE 1931 color space, by first calculating the tristimulus values (X,Y,Z). These values are used to analyse the device transparency color perception of human eyes. The tristimulus values are found using the following expressions [1]:

$$X = \int_{370nm}^{740nm} S(\lambda) \times \bar{x}(\lambda) \times T(\lambda) d\lambda$$

$$Y = \int_{370nm}^{740nm} S(\lambda) \times \bar{y}(\lambda) \times T(\lambda) d\lambda$$

$$Z = \int_{370nm}^{740nm} S(\lambda) \times \bar{z}(\lambda) \times T(\lambda) d\lambda$$

Here, S(λ) is the standard D65 illuminant spectrum, $\bar{x}$, $\bar{y}$, $\bar{z}$ are the color matching functions and T(λ) is the experimental transmittance spectrum. These values are then converted to x,y coordinates in the CIE 1931 color space using the following expression [1]:

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z}$$

As the CIE 1931 color space is two dimensional, only the x and y coordinates are sufficient to express the chromatic content of the device. The x,y coordinates for all devices in this study are plotted in Figure 7(a). On this graph, the achromatic point occurs at ($\frac{1}{3}$, $\frac{1}{3}$). At this achromatic point, which is also referred to as the white point, the perceived color of light passing through the sample is not altered. If the calculated coordinates are close to this point, the accuracy of the represented color is high.

3. To calculate CRI, the (x,y) coordinates from the CIE 1931 color space need to be converted to (u,v) coordinates in the CIE1960 color space. These are calculated using the following expressions [2]:

$$u = \frac{4x}{(-2x + 12y + 3)}$$

$$v = \frac{6y}{(-2x + 12y + 3)}$$

4. To account for the adaptive color shift, we need to modify the (u,v) coordinates using the eight test color samples (TCS) specified in the CIE standard [2]. This was performed using the following transformation of the u,v coordinates from i = 1 to 8, where the i value corresponds to the 8 different TCS:

$$u'_{k,i} = \frac{10.872 + 0.404 \times \frac{c_r}{c_k} \times c_{k,i} - 4 \times \frac{d_r}{d_k} \times d_{k,i}}{16.518 + 1.481 \times \frac{c_r}{c_k} \times c_{k,i} - \frac{d_r}{d_k} \times d_{k,i}}$$

$$v'_{k,i} = \frac{5.520}{16.518 + 1.481 \times \frac{c_r}{c_k} \times c_{k,i} - \frac{d_r}{d_k} \times d_{k,i}}$$

Here, c and d are functions defined as [2]:

$$c = \frac{1}{v} \times (4 - u - 10v)$$

$$d = \frac{1}{v} \times (1.708v + 0.404 - 1.481u)$$

In the above equation, the subscript *r* refers to the reference D65 illuminant, whilst *k* is related to the transmitted light from the sample.

5. The coordinates must then be transferred from the CIE 1960 color space to the CIE 1964 uniform space using the following transformation [2]:

$$W^*_{r,i} = 25(Y_{r,i})^{\frac{1}{3}} - 17$$

$$W^*_{k,i} = 25 \times (Y_{k,i})^{\frac{1}{3}} - 17$$

$$U^*_{r,i} = 13W^*_{r,i}(u_{r,i} - u_r)$$

$$U^*_{k,i} = 13W^*_{k,i}(u'_{k,i} - u'_k)$$

$$V^*_{r,i} = 13W^*_{r,i}(v_{r,i} - v_r)$$

$$V^*_{k,i} = 13W^*_{k,i}(v'_{k,i} - v'_k)$$

6. Once the U^*, V^*, W^* coordinates have been calculated in the CIE 1964 uniform space, the Euclidean distance between the coordinates of the reference illuminant *r*, and the transmitted light through the sample, *k* can be calculated.

$$\Delta E_i = \sqrt{(U^*_{r,i} - U^*_{k,i})^2 + (V^*_{r,i} - V^*_{k,i})^2 + (W^*_{r,i} - W^*_{k,i})^2}$$

7. Using this distance between coordinates, the color rendering index (CRI) for each of the 8 TCSs can be calculated from the CIE standard. This is called the *special CRI*.

$$R_i = 100 - 4.6 \times \Delta E_i$$

8. Finally, to calculate the *general CRI*, find the average of the 8 special CRI values.

$$CRI = \frac{1}{8}\sum_{i=1}^{8} R_i$$

Supporting Figures

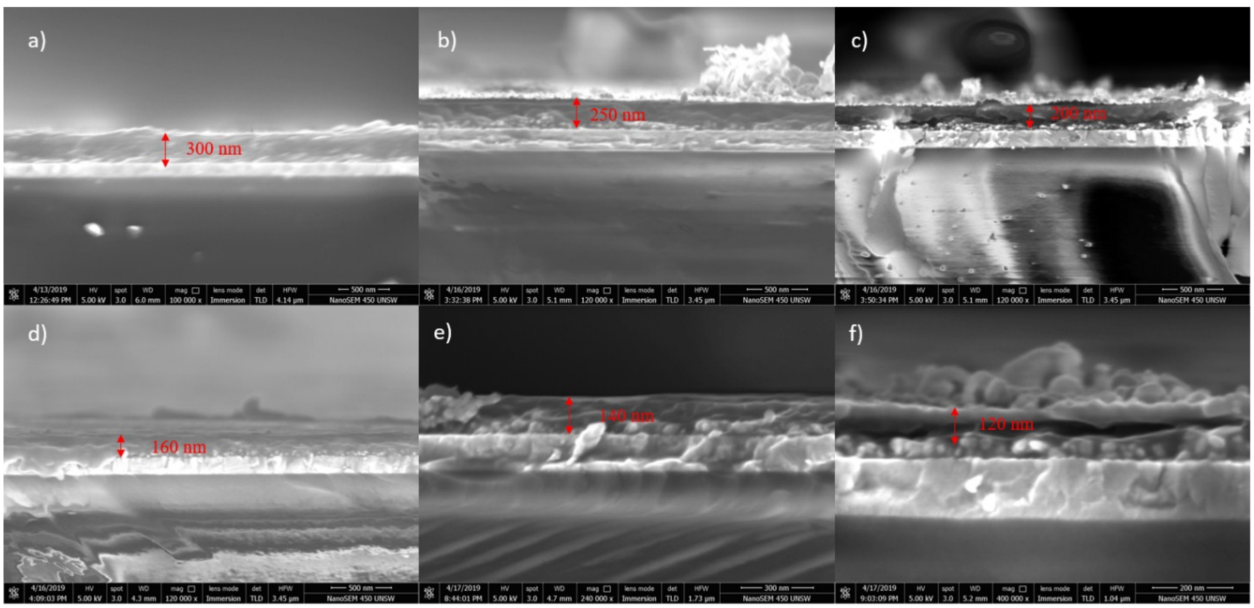


Figure S1. Cross-section SEM images with the estimated active layer thickness for active layer with spin rate of a) 1200 rpm, b) 1500 rpm, c)1800 rpm, d) 2400 rpm, e) 3000 rpm and f) 4000 rpm on ZnO layer.

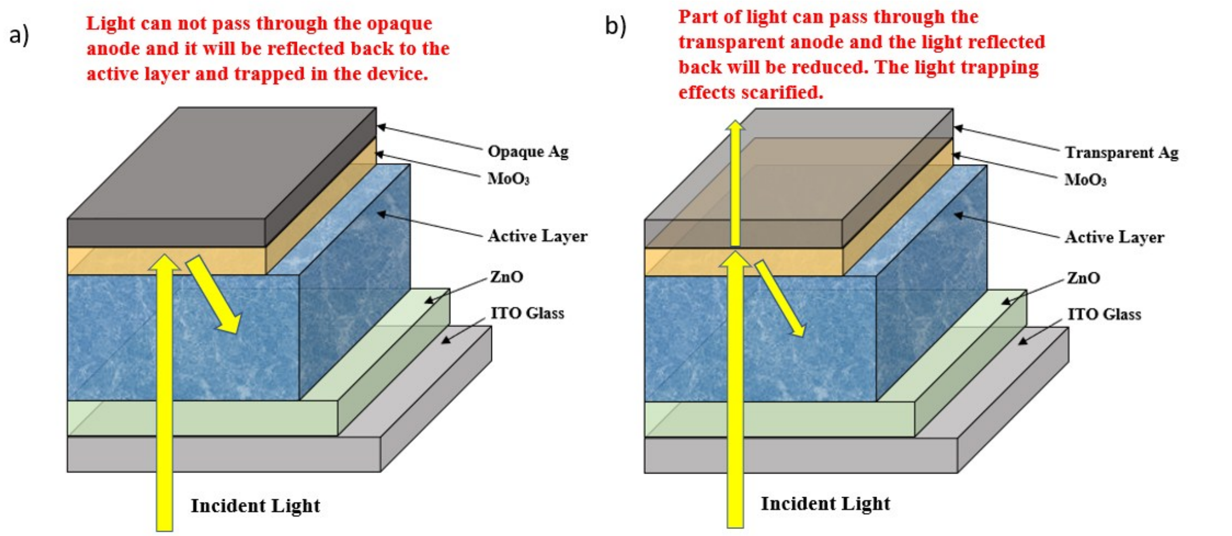
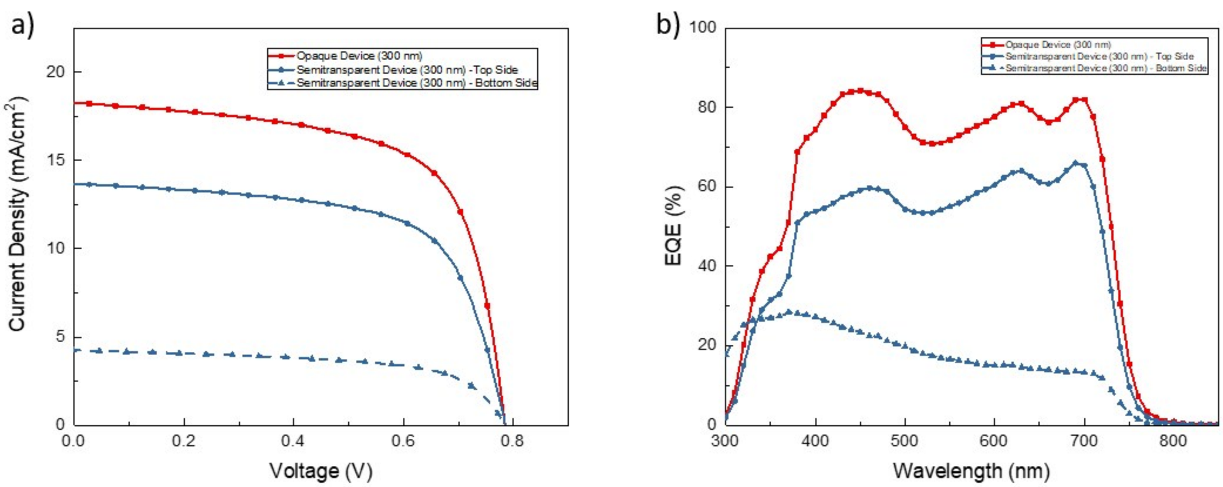


Figure S2. The schematic diagram of the (a) opaque device and (b) semitransparent device. The light reflection and transmission through the anode of both devices are shown with arrows.



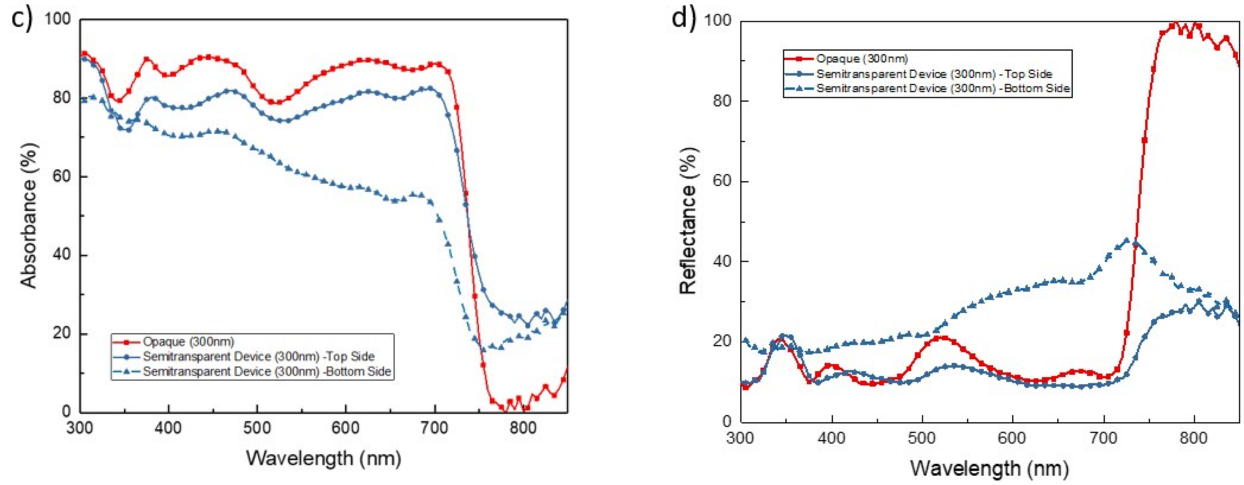


Figure S3. a) current density to voltage (J-V) curves of opaque devices and semitransparent device with active layer of 300 nm illuminated from both bottom (ITO) side and top (Ag) side. b) External quantum efficiency spectrum of opaque devices and semitransparent device with active layer of 300 nm illuminated from both bottom (ITO) side and top (Ag) side. c) Absorption spectrum of opaque devices and semitransparent device with active layer of 300 nm illuminated from both bottom (ITO) side and top (Ag) side. d) Reflectance spectrum of opaque devices and semitransparent device with active layer of 300 nm illuminated from both bottom (ITO) side and top (Ag) side.

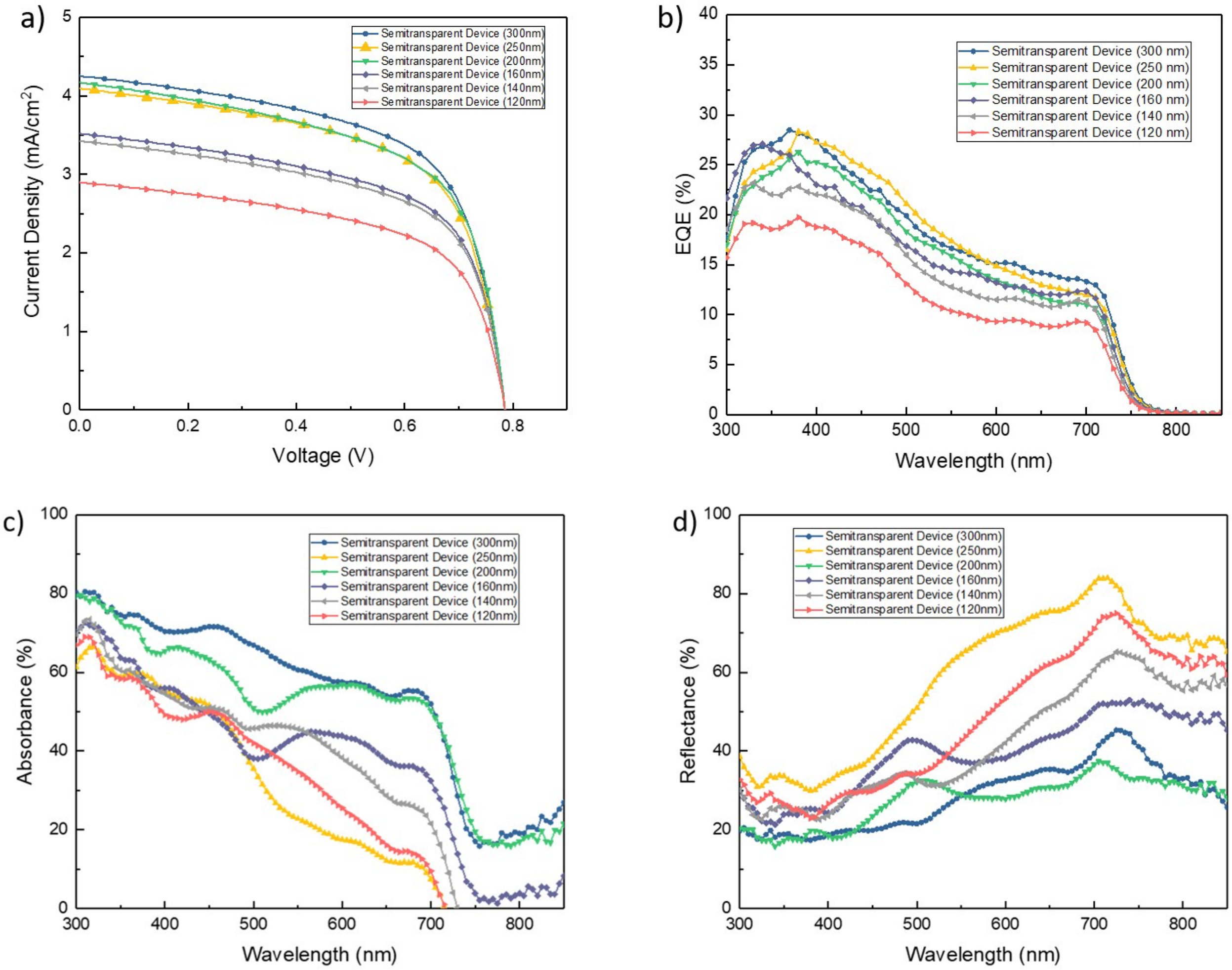


Figure S4. a) current density to voltage (J-V) curves of semitransparent device with different active layer thickness illuminated from top (Ag) side. b) External quantum efficiency spectrum of semitransparent device with different active layer thickness illuminated from top (Ag) side. c) Absorption spectrum of semitransparent device with different active layer thickness illuminated from top (Ag) side. d) Reflectance spectrum of semitransparent device with different active layer thickness illuminated from top (Ag) side.

Supporting Table

Table S1. Photovoltaic parameters including open circuit voltage (V_{oc}), short circuit current density (J_{sc}), fill factor (FF), power conversion efficiency(PCE), series resistance (R_s) and shunt resistance (R_{sh}) obtained from at least five devices for all devices illuminated from Top (Ag) side.

Devices	**Spin rate**	V_{oc}	J_{sc}	**FF**	**PCE**	R_S	R_{SH}
Opaque device	1200 rpm	0.723±0.002	4.12±0.12	60.652±0.625	1.81%±0.07%	18.59±0.86	1150.20±83.13
Semitransparent device (300 nm)	1200 rpm	0.732±0.003	4.19±0.39	59.486±2.301	1.83%±0.24%	19.62±3.33	1082.70±125.54
Semitransparent device (250 nm)	1500 rpm	0.737±0.004	3.87±0.44	62.510±5.293	1.77%±0.14%	18.18±2.57	1156.50±177.08
Semitransparent device (200 nm)	1800 rpm	0.737±0.006	3.44±0.15	56.906±2.630	1.45%±0.12%	25.83±5.94	1107.90±105.31
Semitransparent device (160 nm)	2400 rpm	0.743±0.002	3.31±0.11	59.836±0.400	1.47%±0.05%	21.02±0.99	1287.00±22.72
Semitransparent device (140 nm)	3000 rpm	0.732±0.020	2.80±0.09	58.978±1.762	1.20%±0.05%	27.36±5.72	1447.20±121.61
Semitransparent device (120 nm)	4000 rpm	0.723±0.002	4.12±0.12	60.652±0.625	1.81%±0.07%	18.59±0.86	1150.20±83.13

References

[1] X. Tian, Y. Zhang, Y. Hao, Y. Cui, W. Wang, F. Shi, H. Wang, B. Wei, W. Huang, Semitransparent inverted organic solar cell with improved absorption and reasonable transparency perception based on the nanopatterned MoO3/Ag/MoO3 anode, NANOP, 9 (2015) 093043-093043.

[2] C.I.d.l.É. International, ISBN 3 900 734 57 7, (1995).