Ultra-thin ZnO film as electron transport layer for realizing high efficiency of organic solar cells

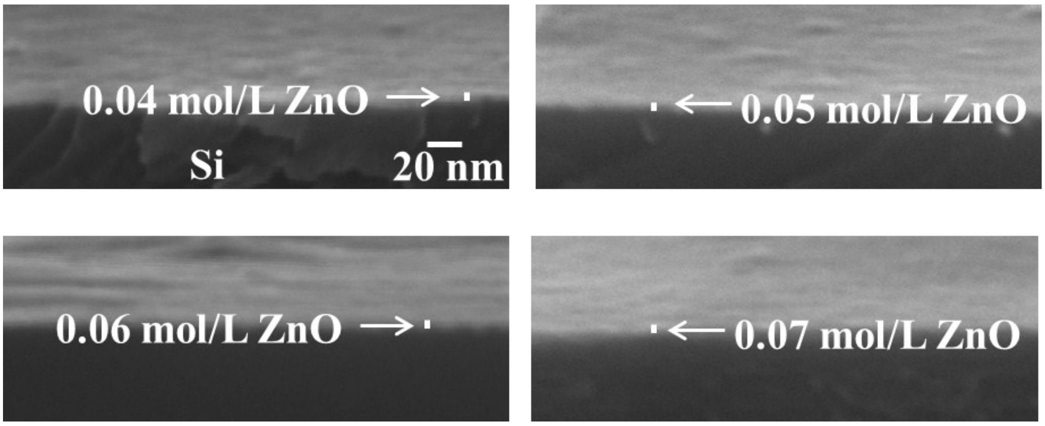

Fig. S1 The cross-sectional scanning electron microscopy images of the ultra-thin ZnO films on bare silicon.

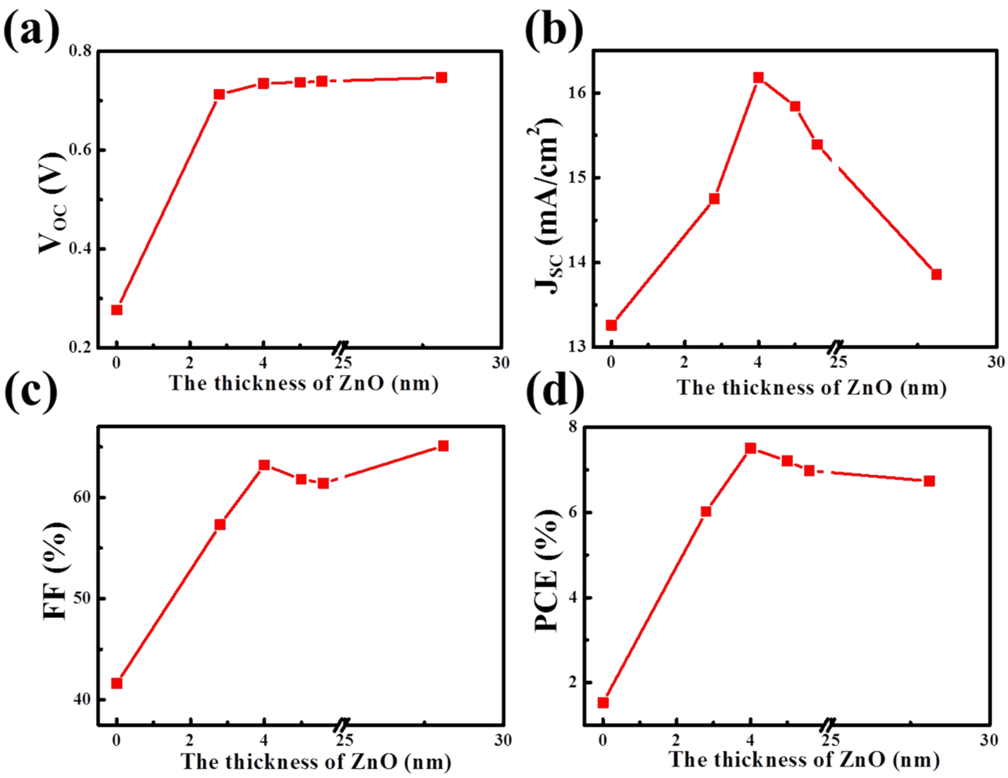

Fig. S2 V_{OC}, J_{SC}, FF and PCE vs. ZnO film thickness (from 0 nm to 28.1 nm).

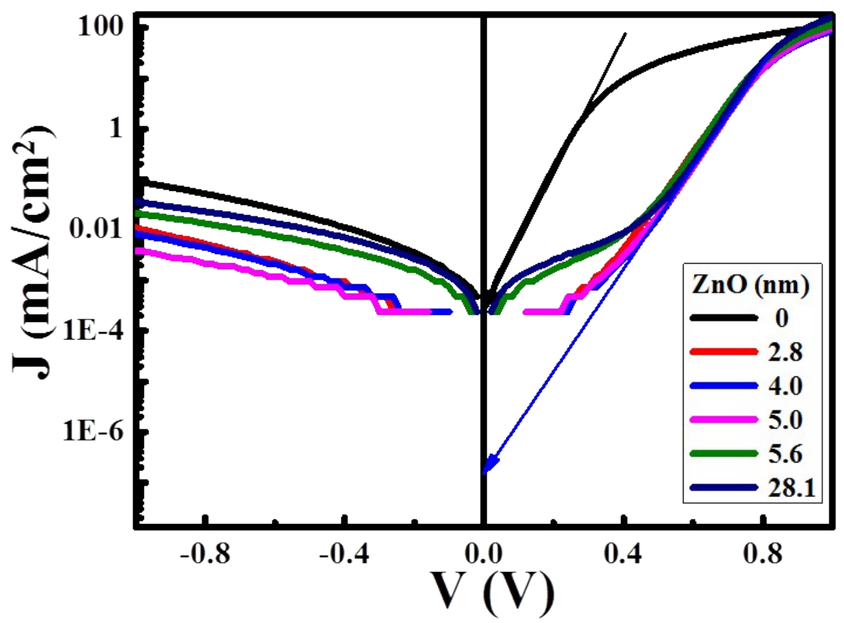

Fig. S3 J–V curves of the devices with different thicknesses of ZnO film in dark.

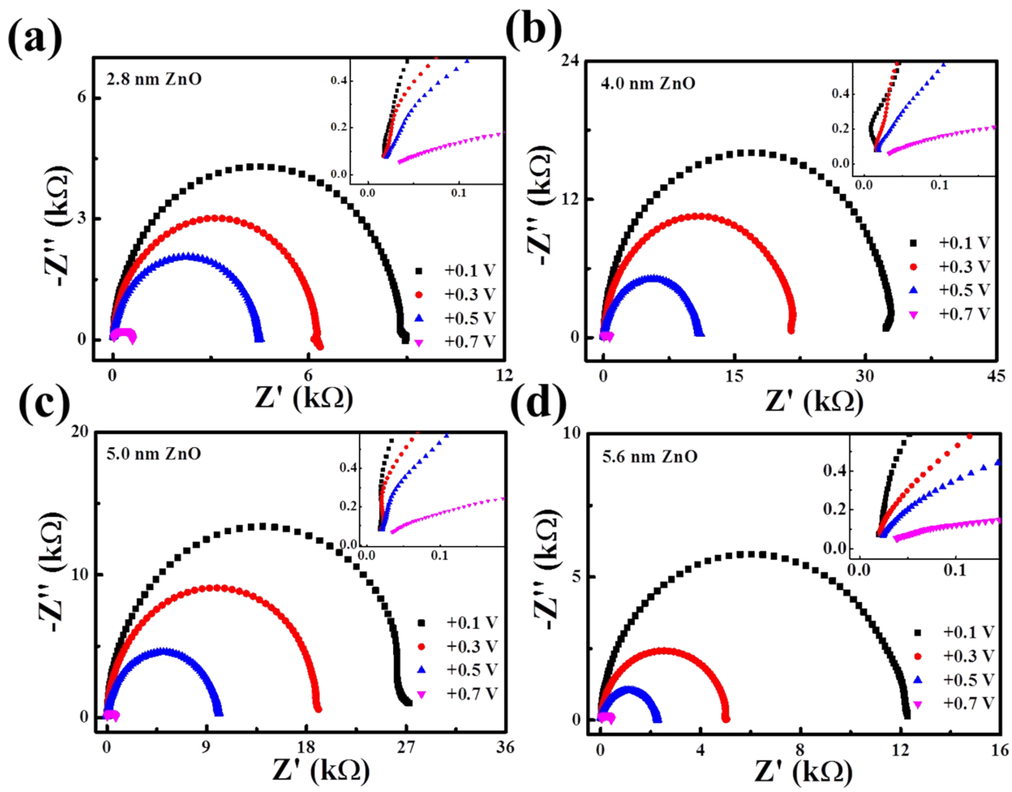

Fig. S4 Impedance spectra of devices with different thicknesses of ZnO film. Nyquist plots of devices under different bias in dark: (a) with 2.8 nm ZnO, (b) with 4.0 nm ZnO, (c) with 5.0 nm ZnO and (d) with 5.6 nm ZnO. Insets show the high frequency part of the plots.

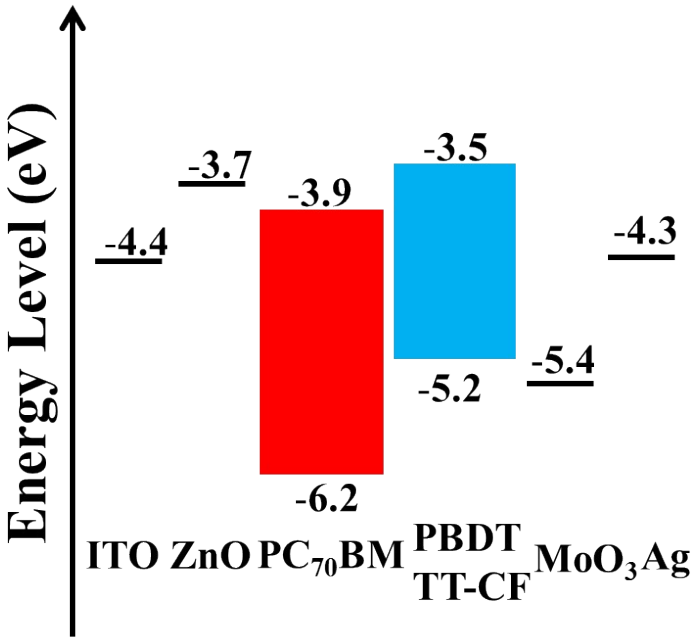

Fig. S5 The schematic energy diagram of the materials.

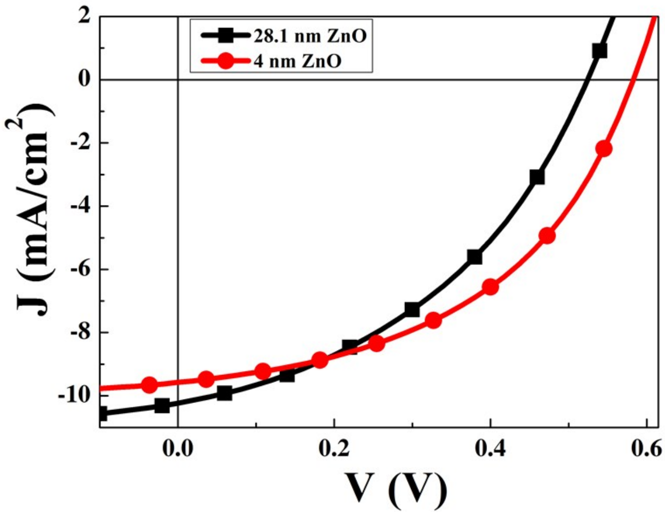

Fig. S6 The J–V curves of the devices with 28.1nm and 4 nm ZnO film.

Table S1 The extracted data of devices with different ZnO film thicknesses for fitting the experimental data of impedance spectroscopy.

ZnO (nm)	**R_s (Ω)**	**R_1 (Ω)**	**R_2 (Ω)**
0	27.57	5235	10.67
2.8	22.45	17810	6155
4.0	14.55	17810	21680
5.0	20.22	17810	17770
5.6	21.01	17810	12669

Table S2 The parameters of bi-exponential model for fitting the photoluminescence decay curves.

The thickness of ZnO film (nm)	**B_1**	**T_1 (ns)**	**B_2**	**T_2 (ns)**	**<τ> (ns)**
0	0.0932	0.666	0.01	4.364	2.193±0.033
2.8	0.1174	0.479	0.0105	3.572	1.717±0.066
4.0	0.161	0.355	0.0078	3.128	1.185±0.102
5.0	0.1629	0.364	0.0063	3.753	1.330±0.082
5.6	0.1361	0.437	0.0075	3.499	1.374±0.047
28.1	0.1422	0.411	0.0078	4.013	1.667±0.054

The fitting was performance with the bi-exponential model:

$$A + B_1 * \exp\left(-\frac{t}{T_1}\right) + B_2 * \exp\left(-\frac{t}{T_2}\right) \qquad \text{(S1)}$$

The lifetime was caculated by:

$$< \tau >= \frac{B_1 \times {T_1}^2 + B_2 \times {T_2}^2}{B_1 \times T_1 + B_2 \times T_2} \qquad \text{(S2)}$$