Supporting Information

Ultrahigh Detectivity Near-Infrared Organic Phototransistor Assistant by Additional Electron Traps sites in Dielectric Layer

Meihua Shou,* Jiaxin Zheng, Xingpeng Liu, Jiadong Zhou, Zengqi Xie, Qing Liao,* Haiou Li,* and Linlin Liu*

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1. Absorption spectrum of OPTs

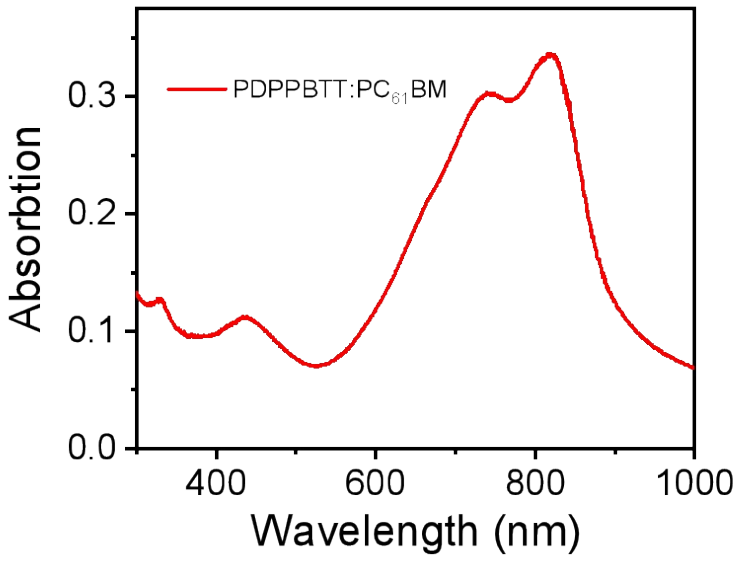

Fig. S1 Absorption spectrum of PDPPBTT:$PC_{61}BM$ 5:1 films

The transmission values of PDPPBTT:$PC_{61}BM$ D/A 5:1 under illumination of 820 nm is 36%. The molar absorption coefficient of polymer PDPPBTT is calculated by Lambert-Beer law:

$$A = \log\left(\frac{1}{T}\right) = \varepsilon bc \tag{S1}$$

Where *A* is the absorbance, *T* is the transmittance, *b* is the absorption layer thickness (unit: cm), *c* is the concentration of the absorption material (unit: mol L^{-1}). With *A* = 0.44, *b* = 1 cm, *c* = 3.83 $\times 10^{-7}$ mol L^{-1}, get a value ε = 1.15 $\times 10^{6}$ L mol^{-1} cm^{-1}.

2. Properties and morphology of ZnO-NPs films

In a 500-mL, three-necked flask, zinc acetate dihydrate (2.95 mg), methanol (125 mL), and a magnetic stirring bar were placed. Potassium hydroxide (1.48 g) dissolved in methanol (65 mL). Potassium hydroxide solution was introduced and bubbled into the reaction mixture with vigorous stirring at 60 ℃ for 2 h. After the reaction was complete, appeared white precipitate, and heat for another 0.5 hours, then the resultant mixture was let stand in air at ambient temperature for 2 h. Aspirate the upper solution, add methanol (50 mL), and stir for 10 minutes. The resultant mixture was let stand in air at ambient temperature for 12 h, and aspirate the upper solution for further purification. Add methanol (50 mL), and stir for 10 minutes. Centrifugation (2000 rpm, 10 min), aspirate the upper solution, and add 2-Methoxyethanol and ethanolamine (volume ratio 20000:548) to configure 5 different concentrations ZnO-NPs solution.[1, 2]

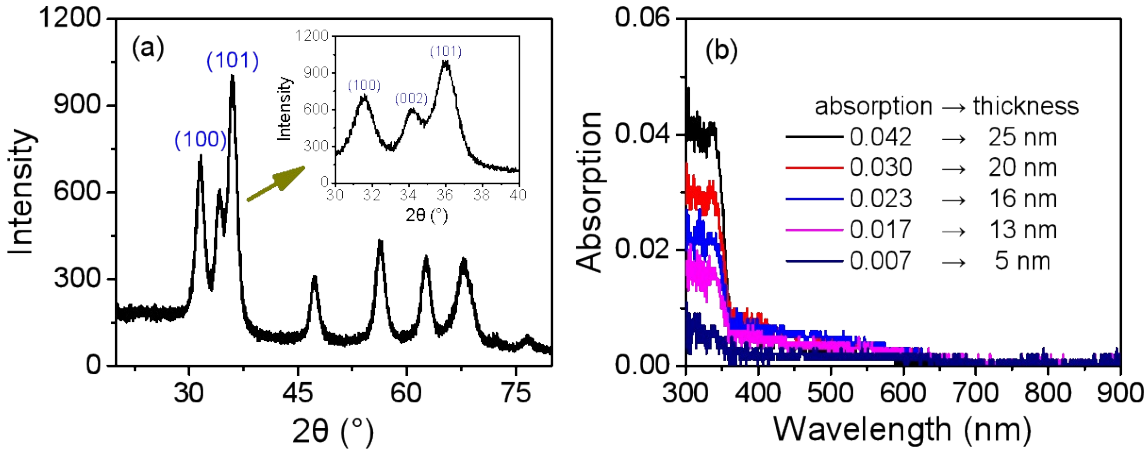

Fig. S2 (a) XRD patterns for the ZnO-NPs, (b) absorption spectrum of ZnO-NPs films with different thicknesses

The size of ZnO-NPs can be obtained from the X-ray diffraction spectrum (XRD, Figure S2a). It can be seen from the XRD spectrum that the half-height width (β) values of the diffraction peaks corresponding to the three peaks (100), (002) and (101) are 1.605, 1.556 and 1.736

respectively, and the corresponding diffraction angles (ϑ) are 15.884, 17.211 and 18.126 respectively. According to the Scherrer formula:

$$D = \frac{K\lambda}{\beta \cos\theta} \tag{S2}$$

where *K* is the Scherrer constant (0.89), λ is the X-ray wavelength (1.54056 Å). The average particle size (*D*) of ZnO-NPs grains perpendicular to the crystal plane direction can be calculated in equation S2. The calculated *D* values are 5.08 nm, 5.28 nm and 4.76 nm respectively, indicating that zinc oxide is an ellipsoid with a particle size of approximately 5 nm.

The film thicknesses of ZnO-NPs were measured by a Dektak 150 from Veeco USA when the thickness was larger than 20 nm. However, the film thicknesses are below than the measurement range of the Dektak 150 as the thickness of the ZnO-NPs film is less than 20 nm. Among the ZnO-NPs films with five thicknesses we prepared, after measuring the maximum film thickness, the remaining thickness was calculated by Lambert-Beer's law (Tab. S1). It is known that the absorption of a 25 nm thick ZnO-NPs film is 0.042 (Figure S2b), and the absorption values of different thicknesses of ZnO-NPs films (0.007, 0.017, 0.023, 0.030). The thickness values of the corresponding ZnO-NPs films can be calculated (5 nm, 13 nm, 16 nm, 20 nm, Table S1).

Table S1. The thickness of ZnO-NPs layer calculated from the absorption value according to Lambert Beer's law.

absorption	0.007	0.017	0.023	0.030	0.042
thickness (nm)	5	13	16	20	25

In order to analyze the morphology of ZnO-NPs layer with different thickness more intuitively, atomic force microscopy (AFM) was used to measure the morphology of ZnO-NPs film layers with different thicknesses. As shown in Figure S3, the particle size of ZnO-NPs remains unchanged as the thickness of the ZnO-NPs film layer increases, but the thickness of ZnO-NPs film increases. ZnO-NPs are scattered on the silicon wafer and are not connected into sheets

when the thickness of ZnO-NPs is 5 nm (Figure S3a). ZnO-NPs cover the entire surface as the thickness of ZnO-NPs increases to 13 nm, and the stacking thickness increases significantly as the thickness of ZnO-NPs increases. In addition, as the thickness of ZnO-NPs increases, the roughness of the film increases (Table S2), but ZnO-NPs do not aggregate.

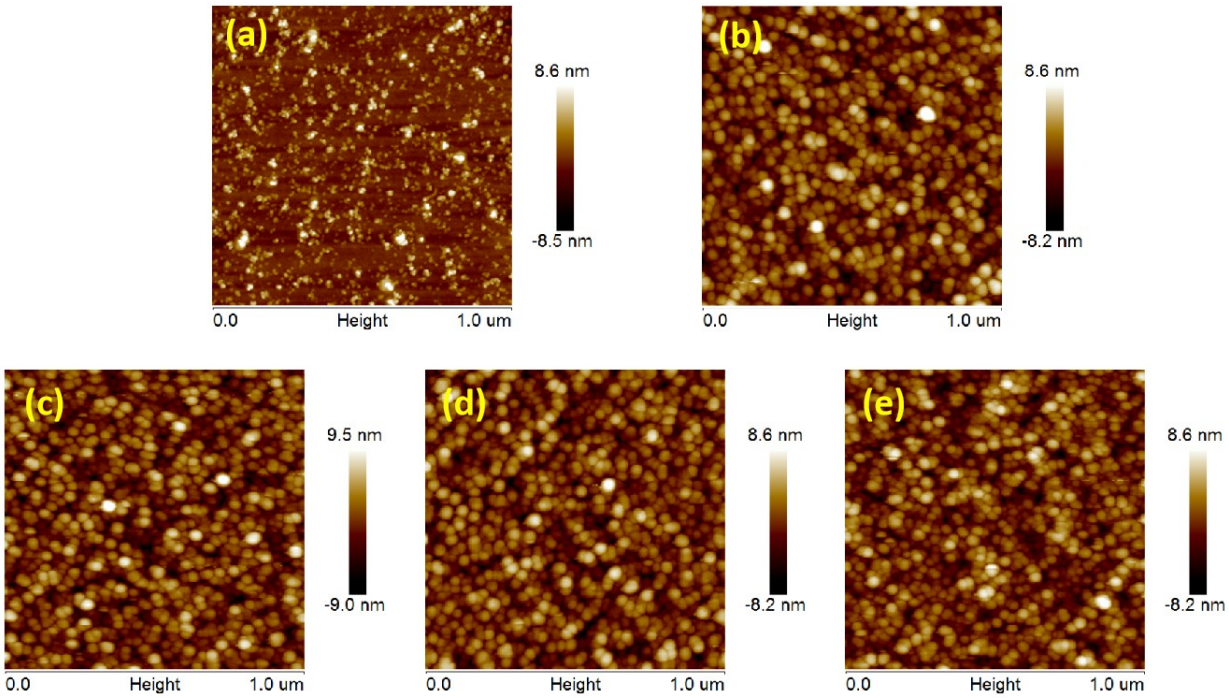

Fig. S3 The atomic force microscope morphology (AFM) images of ZnO-NPs layer with thickness of: (a) 5 nm, (b) 13 nm, (c) 16 nm, (d) 20 nm, (e) 25 nm.

Table S2. The root-mean-square (RMS) roughness of the ZnO-NPs layer surfaces with different thickness.

thickness (nm)	5	13	16	20	25
RMS	1.74	2.05	2.26	2.32	2.37

3. Semiconductor characteristic parameters of the phototransistors

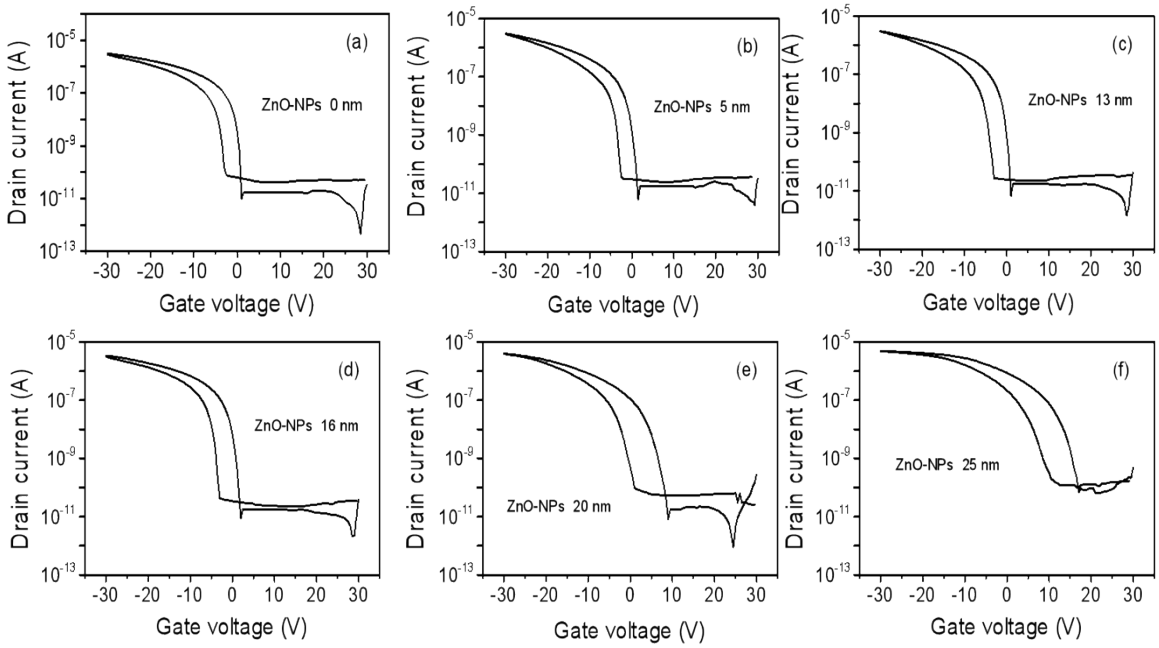

Fig. S4 Transfer characteristics curves of OPTs with different thickness of ZnO-NPs (a) 0 nm, (b) 5 nm, (c) 13 nm, (d) 16 nm, (e) 20 nm, (f) 25 nm, the drain-source voltages are set to -60 V.

Table S3. The mobility (hole saturation mobility in the dark) of OPTs with different thickness of ZnO-NPs.

	ZnO-NPs (nm)					
	0	5	13	16	20	25
V_{th0} (V)	2	2	2	3	9	17
V_{thI} (V)	-2	-2	-2	-2	-1	6
ΔV_{th} (V)	4	4	4	5	10	11
I_{on}/I_{off} ($\times 10^5$)	2	2	2	2	1.5	1
μ ($cm^2\ V^{-1}\ s^{-1}$)	0.11	0.11	0.11	0.12	0.10	0.07

4. Transfer and output characteristics curves of the phototransistors

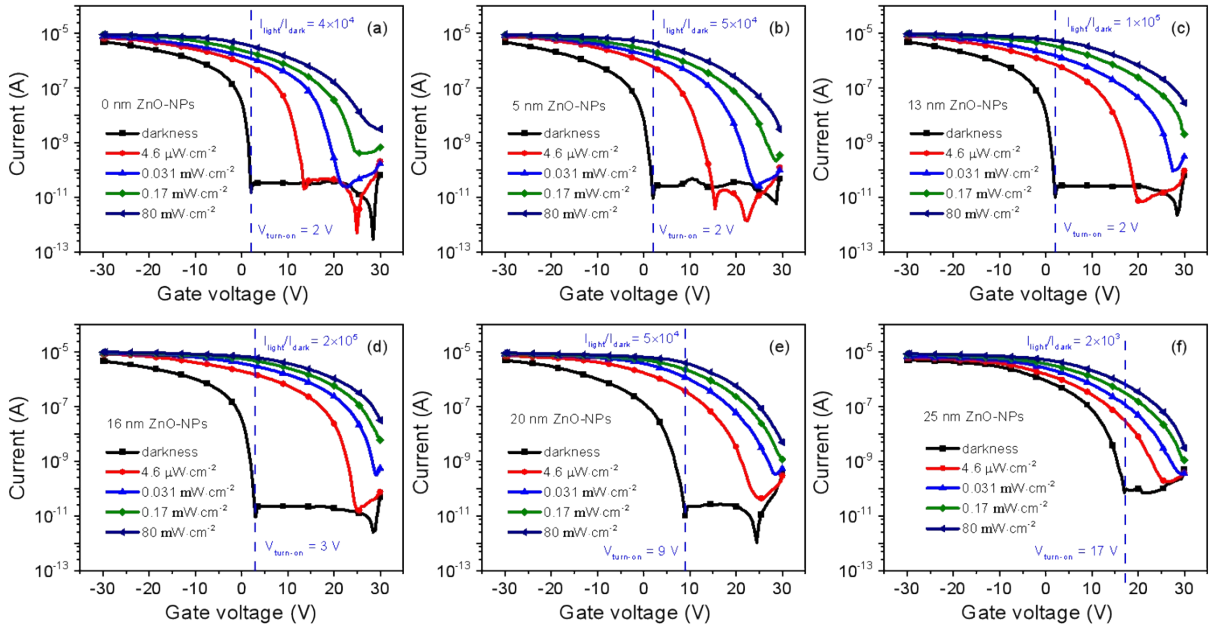

Fig. S5 Transfer characteristics curves without illumination and in different light intensity illumination of 820 nm of OPTs with different ZnO-NPs thickness: (a) 0 nm, (b) 5 nm, (c) 13 nm, (d) 16 nm, (e) 20 nm, (f) 25 nm, the drain voltage is set to -60 V.

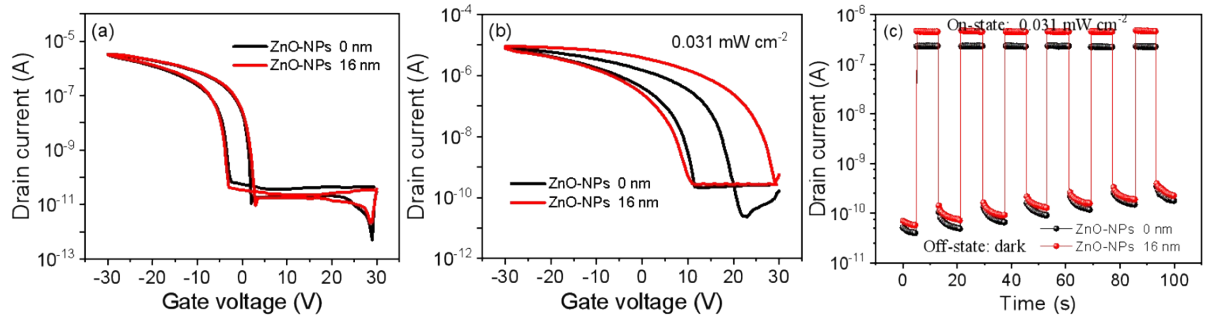

Fig. S6 Transfer characteristics curves of OPTs in dark (a) and under 0.031 mW cm^{-2} illumination (b) with 0 nm and 16 nm ZnO-NPs, the drain-source voltages are set to -60 V, (c) the reproducible on/off switching properties of OPTs with 0 nm and 16 nm ZnO-NPs, 0.031 mW cm^{-2} at 820 nm, the drain-source voltages are set to -60 V.

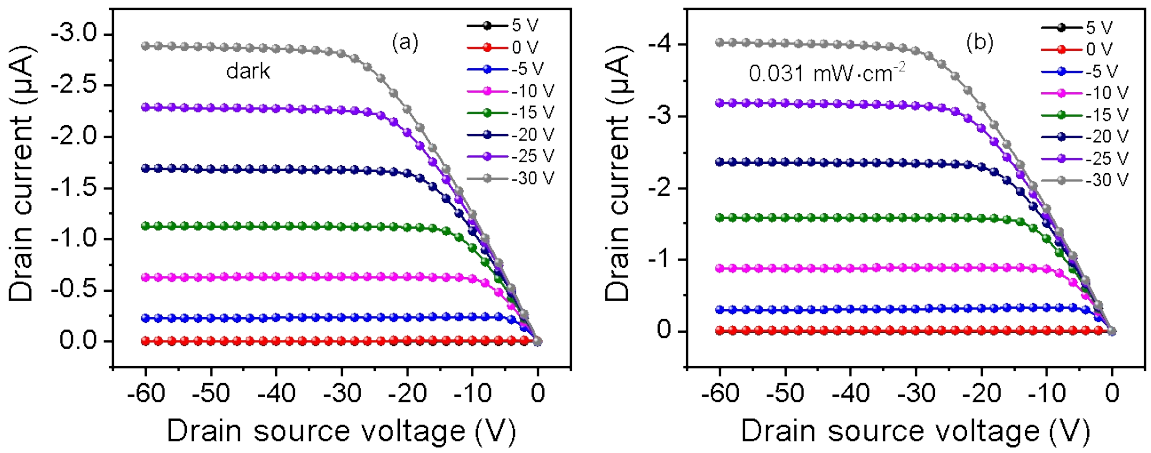

Fig. S7 Output characteristics curves without illumination (a) and under 0.031 mW cm^{-2} of illumination at 820 nm (b) of 16 nm ZnO-NPs OPTs at different gate voltages.

5. The evolution of R, G and D* as a function of gate voltage

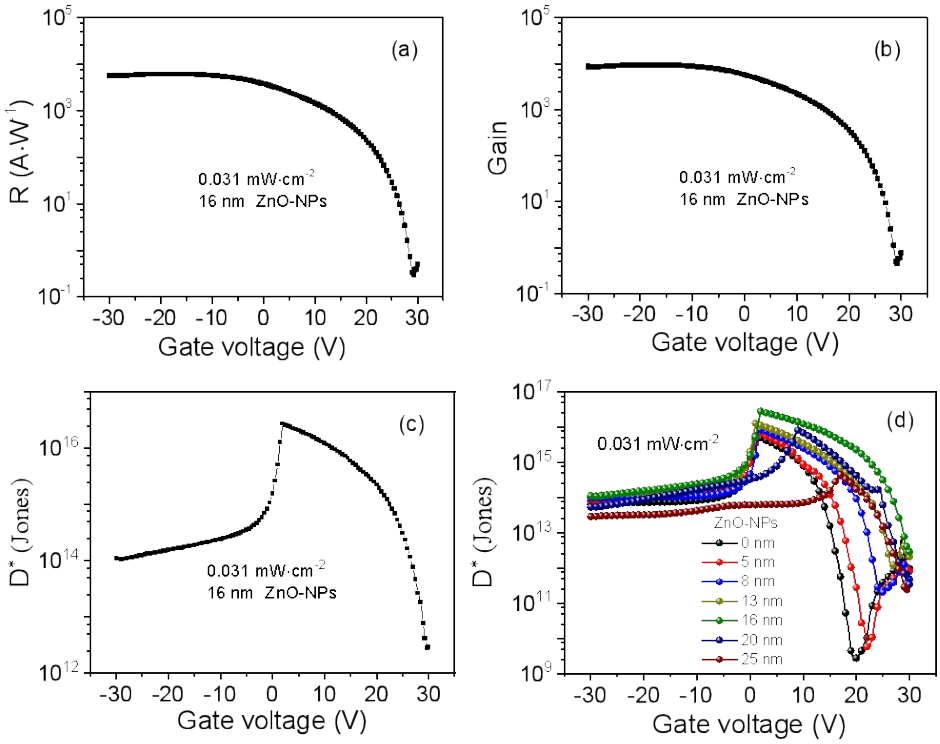

Fig. S8 (a-c) Dependence of the responsivity, gain and detectivity on the gate voltage under 0.031 mW cm^{-2} illumination with -60 V drain voltage of OPTs with 16 nm ZnO-NPs, (d) variation of D^*_{shot} (0.031 mW cm^{-2} of 820 nm) with gate voltage in OPTs with different ZnO-NPs thickness.

6. The noise spectral power

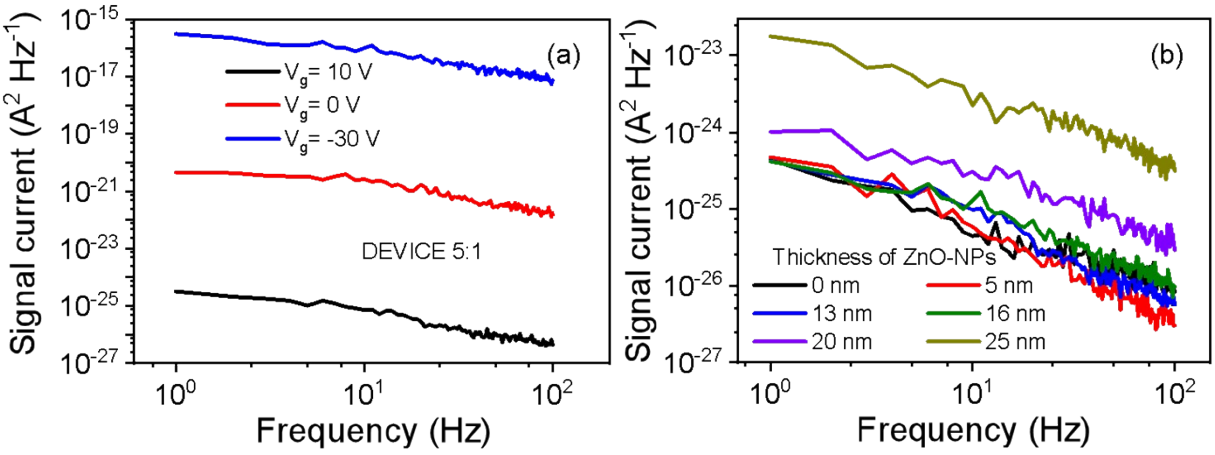

Fig. S9 The noise spectral power of (a) the DEVICE 5:1 with 10 V, 0 V and -30 V gate voltage and -60 V drain source voltage, and (b) OPTs with different ZnO-NPs thicknesses at V_g =$V_{on\text{-}dark}$ (V_{on} in dark) and -60 V drain source voltage, showing the frequency dependence of the noise density at frequencies <100 Hz.

7. Time responses of OPTs

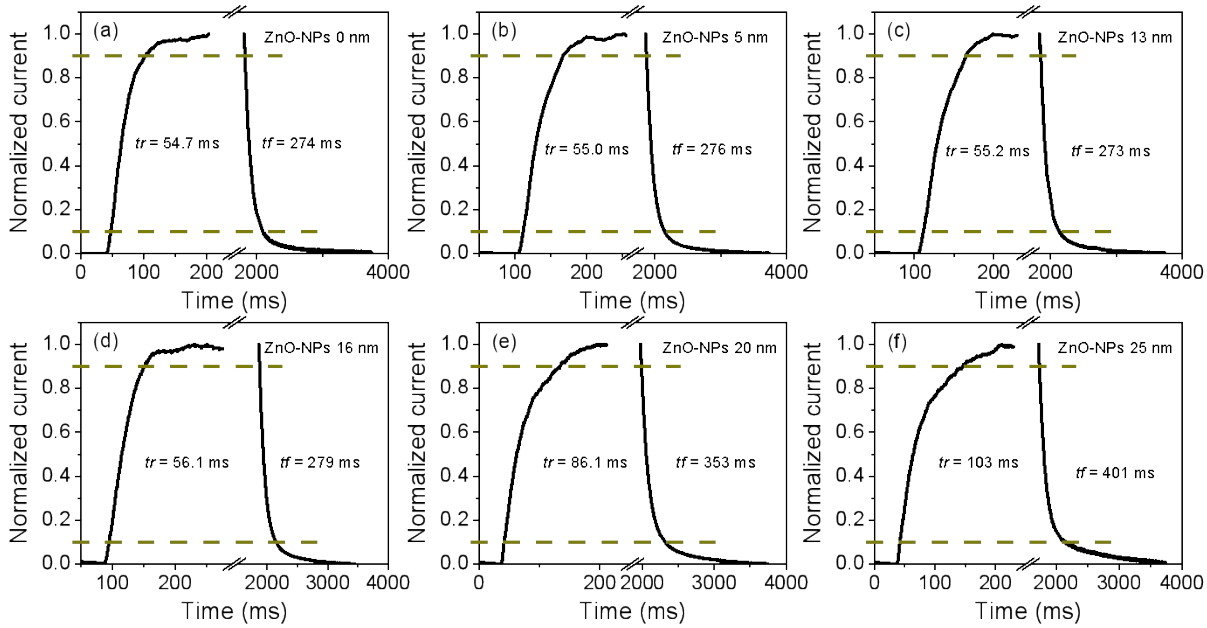

Fig. S10 Time responses (80 mW cm^{-2} at 820 nm) of OPTs with different thickness of ZnO-NPs: (a) 0 nm ZnO-NPs, (b) 5 nm ZnO-NPs, (c) 13 nm ZnO-NPs, (d) 16 nm ZnO-NPs, (e) 20 nm ZnO-NPs, (f) 25 nm ZnO-NPs, the drain and gate voltage were set to -60 V and 10 V (20 V in OPTs with 25 nm ZnO-NPs) respectively.

8. Optical response properties of OPTs with different PMMA thickness

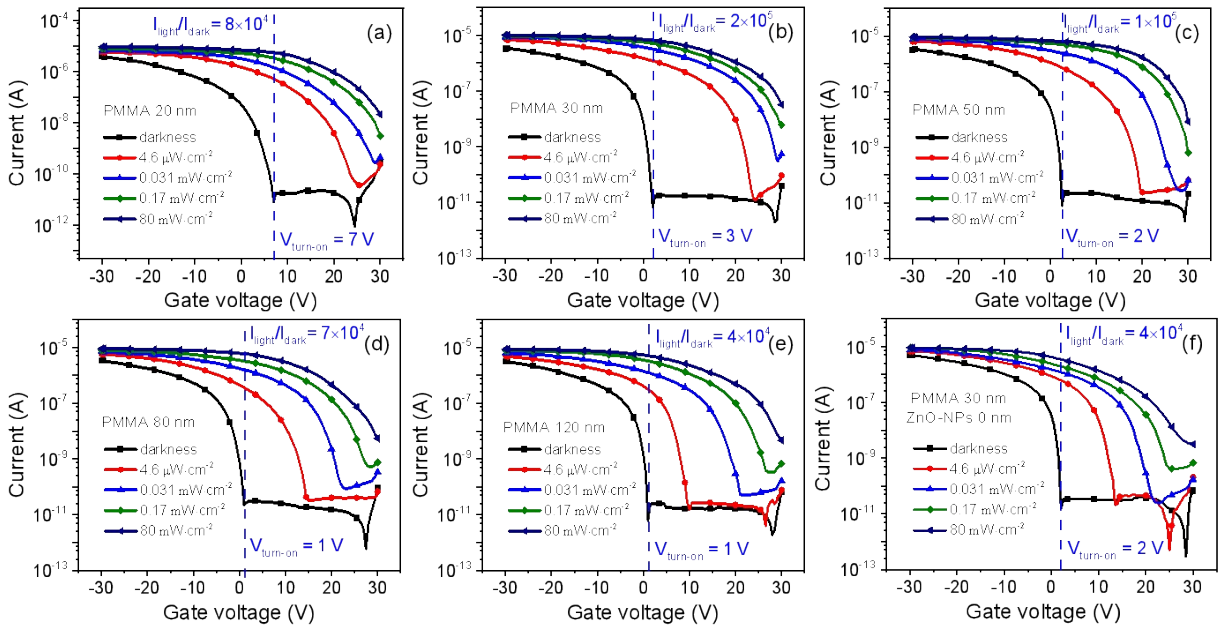

Fig. S11 Transfer characteristics curves (without illumination and in different light intensity illumination of 820 nm) of OPTs with 16 nm ZnO-NPs and different PMMA thickness: (a) 20 nm, (b) 30 nm, (c) 50 nm, (d) 80 nm, (e) 120 nm, (f) 30 nm without ZnO-NPs, the drain voltage is set to -60 V.

Table S4. The V_{on} and I_{light}/I_{dark} of OPTs with different thickness of PMMA.

	PMMA (nm)				
	20	30	50	80	120
V_{on} (V) in dark	7	3	2	1	1
V_{on} (V) in light	29	29	26	22	21
ΔV_{on} (V)	22	26	24	21	20
I_{light}/I_{dark} (×10^5 A)	0.8	2	1	0.7	0.4

OPTs with 16 nm ZnO-NPs. Concrete parameters of OPTs at -60 V drain voltage, $\Delta V_{on} = V_{on\text{-}light}\text{-}V_{on\text{-}dark}$, I_{light}/I_{dark} were measured at $V_g = V_{on\text{-}dark}$ under 0.031 mW cm^{-2} illuminations.

9. Optical response properties of OPTs with different active layer

The structure of OPT is a bottom-gate, top-contact, field effect transistor (FET) configuration, as follows: Si/SiO_2/ZnO-NPs/PMMA/Pffbt4t-20D:PC_{61}BM (1:1.2, or PTB7:PC_{61}BM = 5:1)/Au-Au electrodes. The electrode width and length were set as 1000/40 μm, respectively. The thicknesses of the Pffbt4t-20D:PC_{61}BM and PTB7:PC_{61}BM layer were optimized as 140 nm and 80 nm, respectively. The ZnO-NPs were prepared with five different thicknesses of 16 nm and 20 nm, the PMMA were prepared with 30 nm. Beside, ZnO-NPs have light absorption in the wavelength range less than 350 nm, adding ZnO-NPs to OPTs with Pffbt4t-20D:PC_{61}BM and PTB7:PC_{61}BM as the active layer can only slightly enhance the light absorption within 350 nm (Fig. S11b). The incident light wavelength to measured the transfer characteristics of OPTs is 690 nm, therefore, the contribution of the absorption effects of ZnO-NPs in the performance of OPTs should be little.

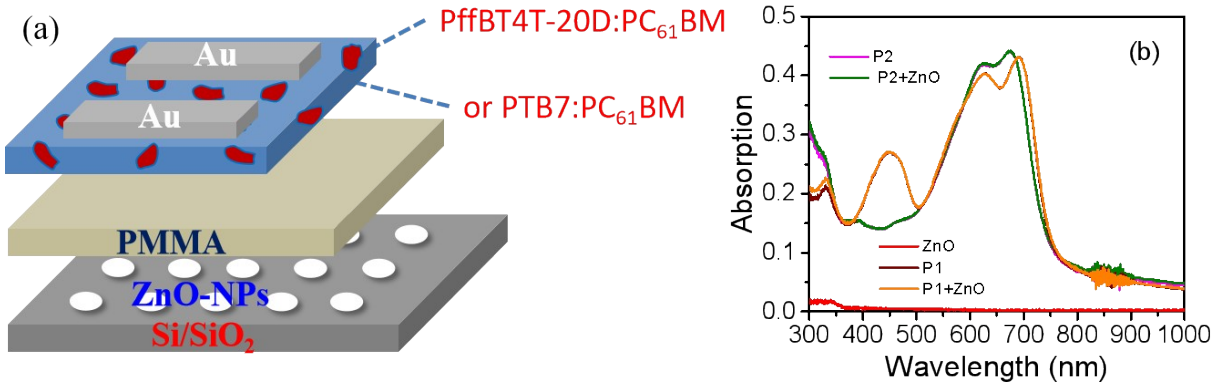

Fig. S12 (a) Device structure of the OPTs with Pffbt4t-20D:PC_{61}BM or PTB7:PC_{61}BM as the active layer, (b) absorption spectrum of ZnO-NPs films, Pffbt4t-20D:PC_{61}BM (P1) films, films including ZnO-NPs and Pffbt4t-20D:PC_{61}BM (P1+ZnO), PTB7:PC_{61}BM (P2) films, films including ZnO-NPs and PTB7:PC_{61}BM (P2+ZnO).

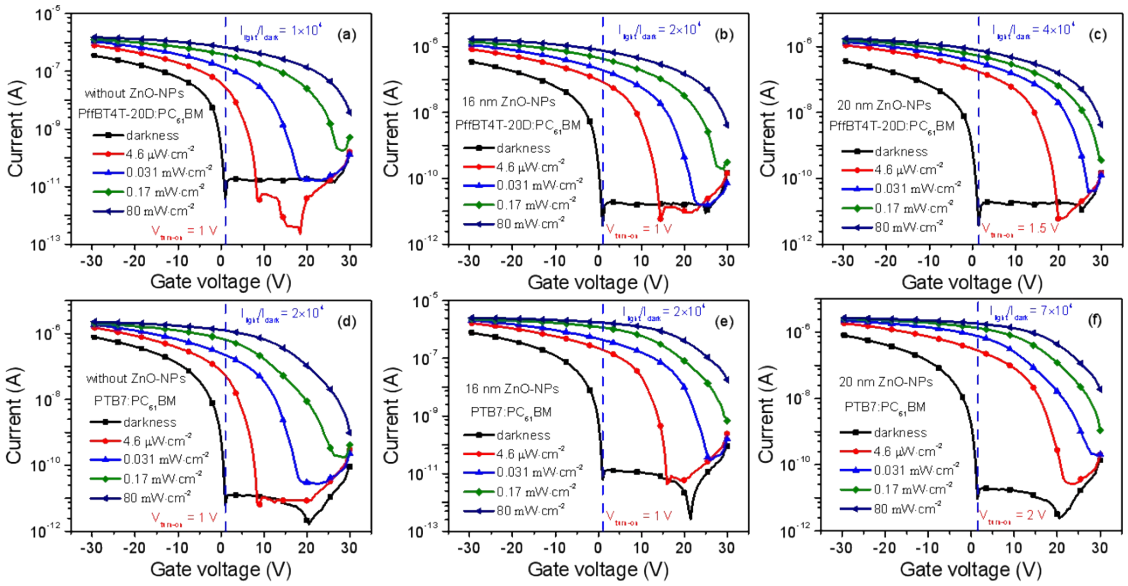

Fig. S13 Transfer characteristics curves (without illumination and in different light intensity illumination of 820 nm) of OPTs with different active layer (Pffbt4t-20D:$PC_{61}BM$, PTB7:$PC_{61}BM$) and different ZnO-NPs thickness: (a-c) Pffbt4t-20D:$PC_{61}BM$ with 0 nm, 16 nm and 20nm ZnO-NPs, (d-f) PTB7:$PC_{61}BM$ with 0 nm, 16 nm and 20nm ZnO-NPs, the drain voltage is set to -60 V.

Table S5. The V_{on}, ΔV_{on} and I_{light}/I_{dark} of OPTs with different active layer and different thickness of ZnO-NPs.

	Pffbt4t-20D:$PC_{61}BM$ (P1)			PTB7:$PC_{61}BM$ (P2)		
ZnO-NPs (nm)	0	16	20	0	16	20
V_{on} (V) in dark	1	1	1.5	1	1	2
ΔV_{on} (V)	18	22	26	17	25	27
I_{light}/I_{dark} ($\times 10^4$)	1	2	4	2	4	7

Concrete parameters of OPTs at -60 V drain voltage under 0.031 mW cm^{-2} illuminations, ΔV_{on} = $V_{on\text{-}light}$-$V_{on\text{-}dark}$, I_{light}/I_{dark} was measured at V_g = $V_{on\text{-}dark}$.

10. Notes and references

1 W. J. E. Beek, M. M. Wienk, M. Kemerink, X. Yang, R. A. J. Janssen. *J. Phys. Chem. B,* 2005, **109**, 9505-9516.

2 D. Liu, T. L. Kelly. *Nat. Photonics,* 2014, **8**, 133-138.