Supporting Information

Retina-inspired controllable neuromorphic vision organic sensors with ultraweak ultraviolet detection

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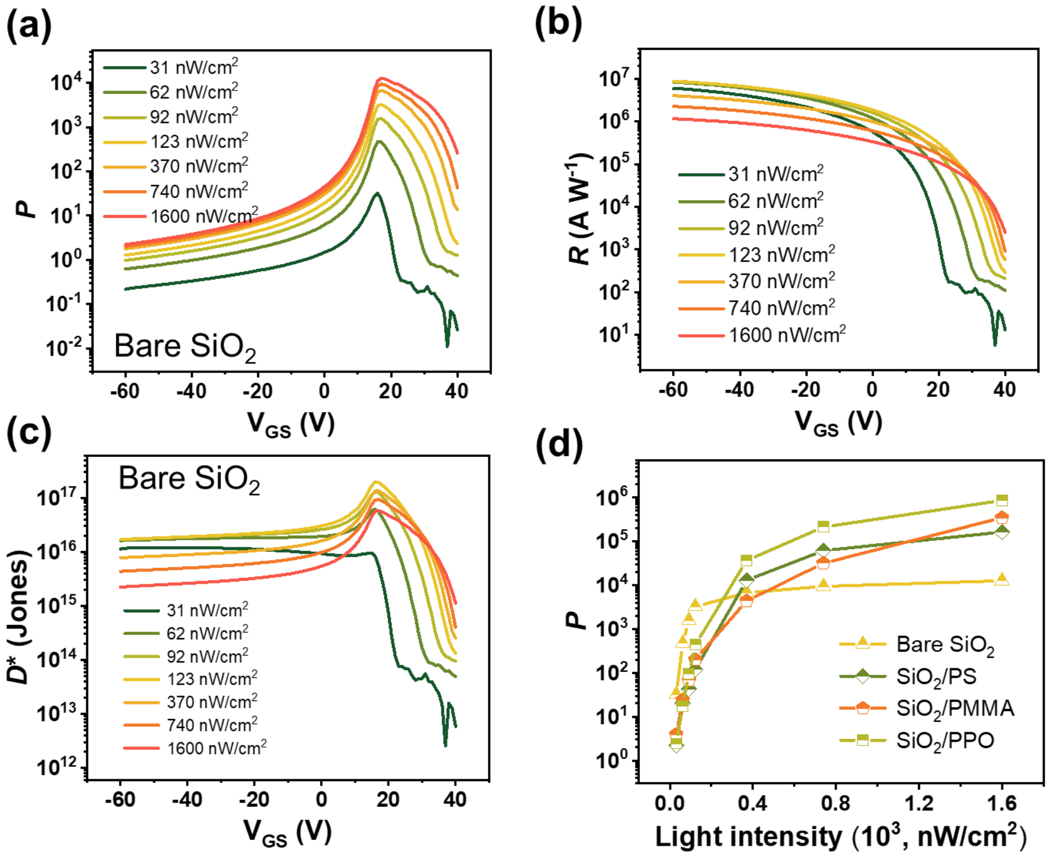

Figure S1. (a~c) P, R and D^* of the phototransistor based on bare SiO_2 dielectric at various illumination intensities. (d) P_{max} in different interface as a function of illumination intensity.

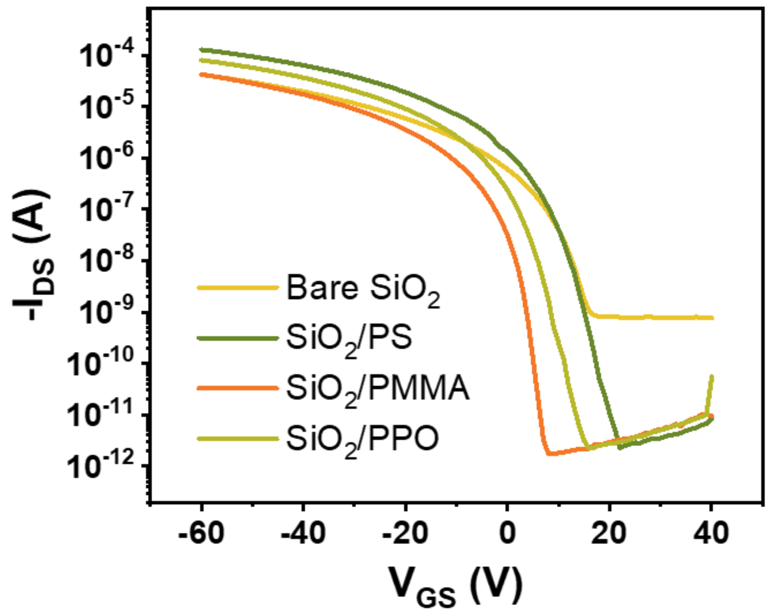

Figure S2. The transfer curves of different interface.

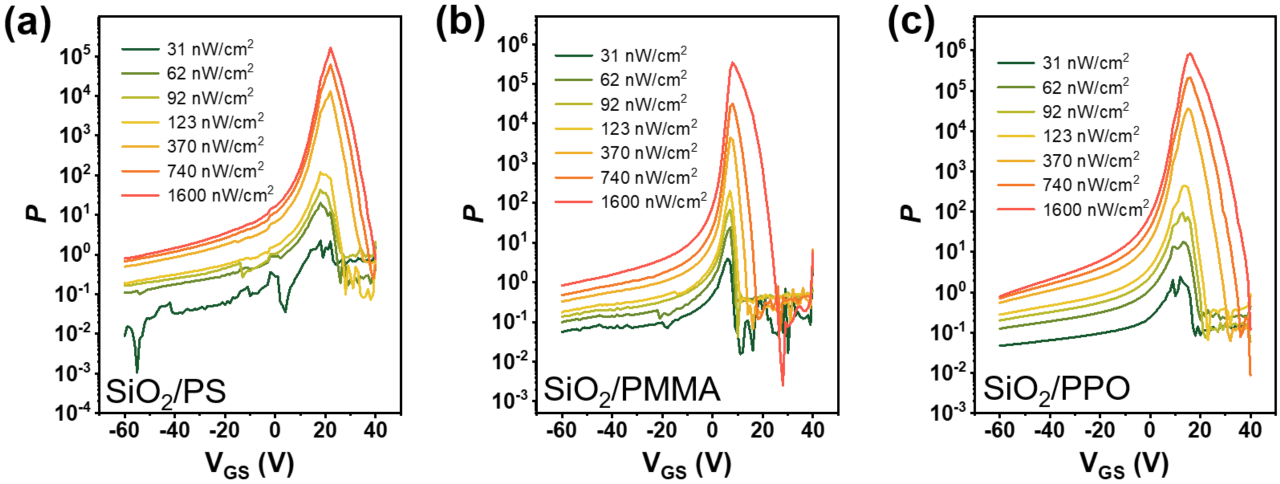

Figure S3. The photosensitivity (P) of the phototransistor based on (a) SiO_2/PS; (b) SiO_2/PMMA; (c) SiO_2/PPO.

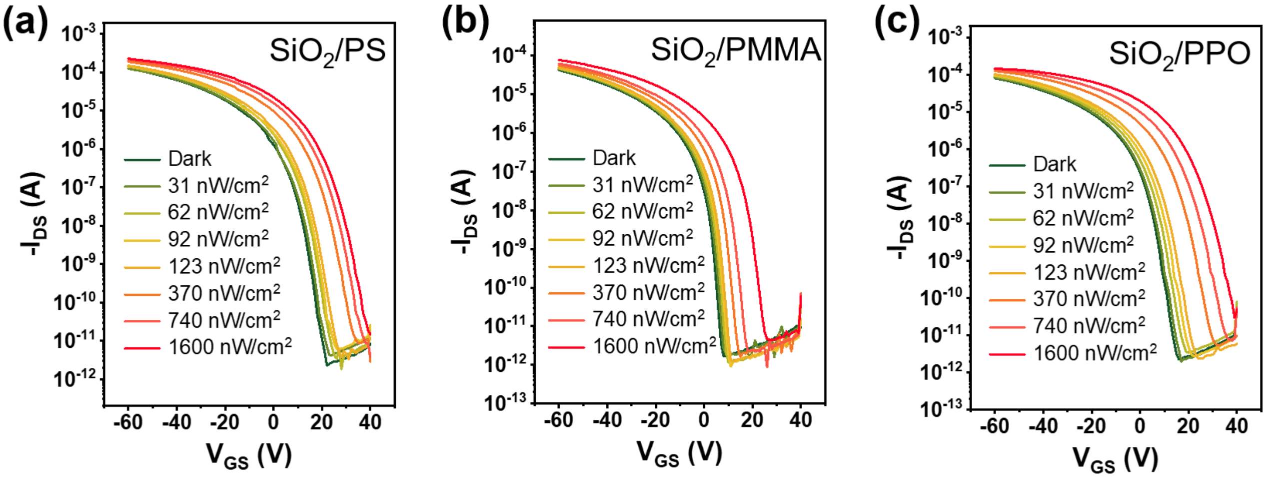

Figure S4. The transfer curves of the UV-sensitive OPTs based on (a) SiO_2/PS; (b) SiO_2/PMMA; (c) SiO_2/PPO.

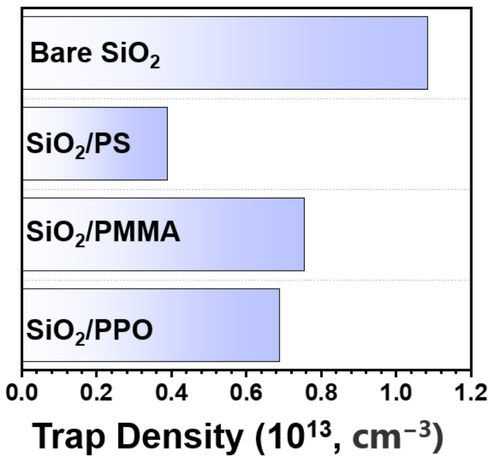

Figure S5. Trap density with bare SiO_2, SiO_2/PMMA, SiO_2/PS, SiO_2/PPO.

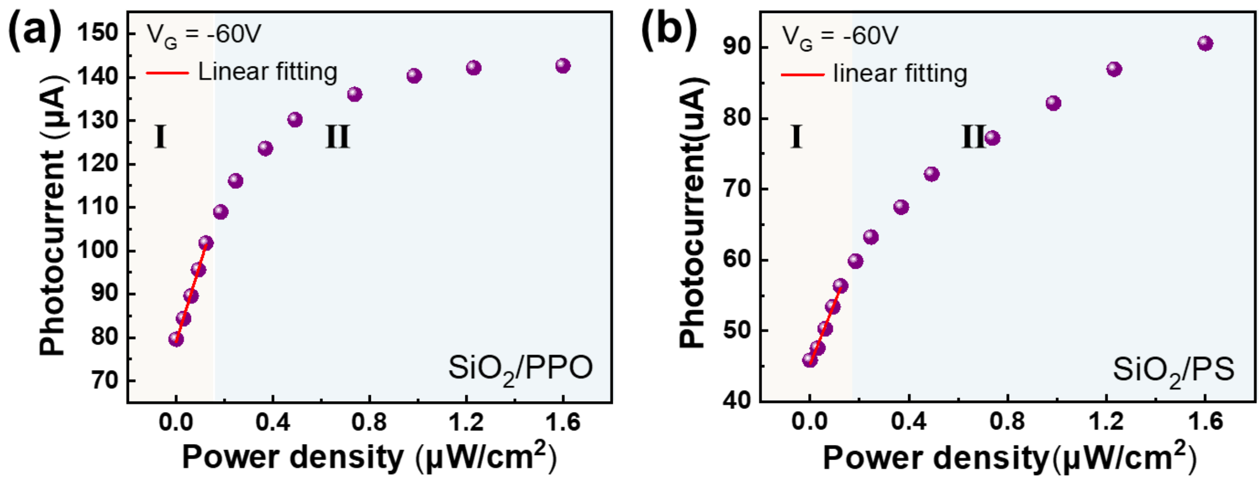

Figure S6. The dependence of photocurrent on light density based on (a) PPO/SiO_2; (b) PS/SiO_2.

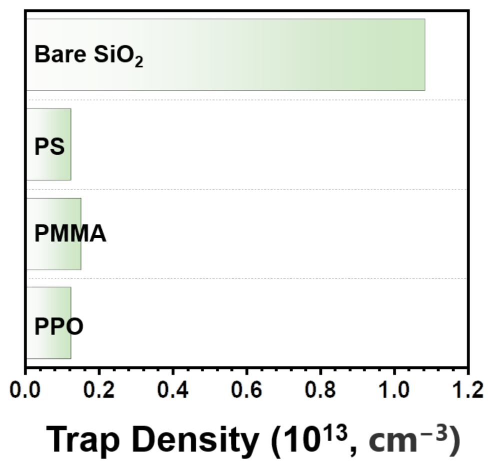

Figure S7. Trap density with bare SiO_2, PS, PMMA, PPO.

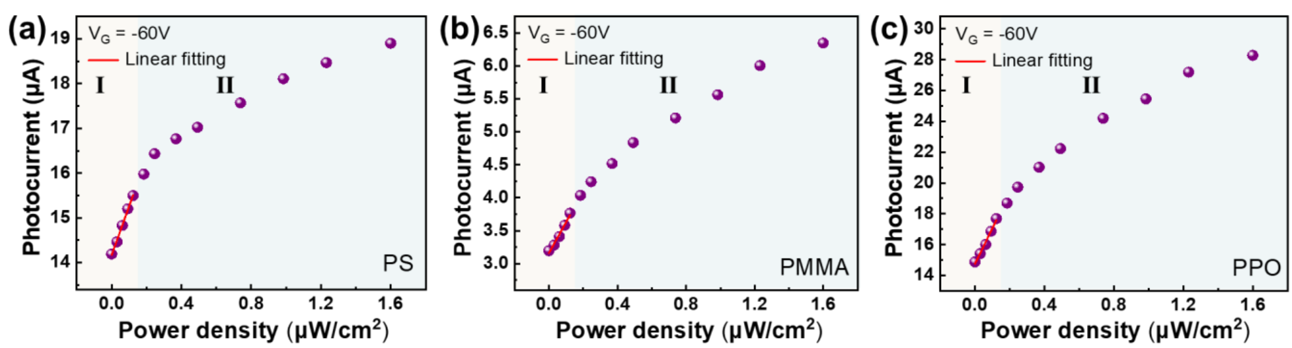

Figure S8. The dependence of photocurrent on light density based on (a) PS; (b) PMMA; (c) PPO.

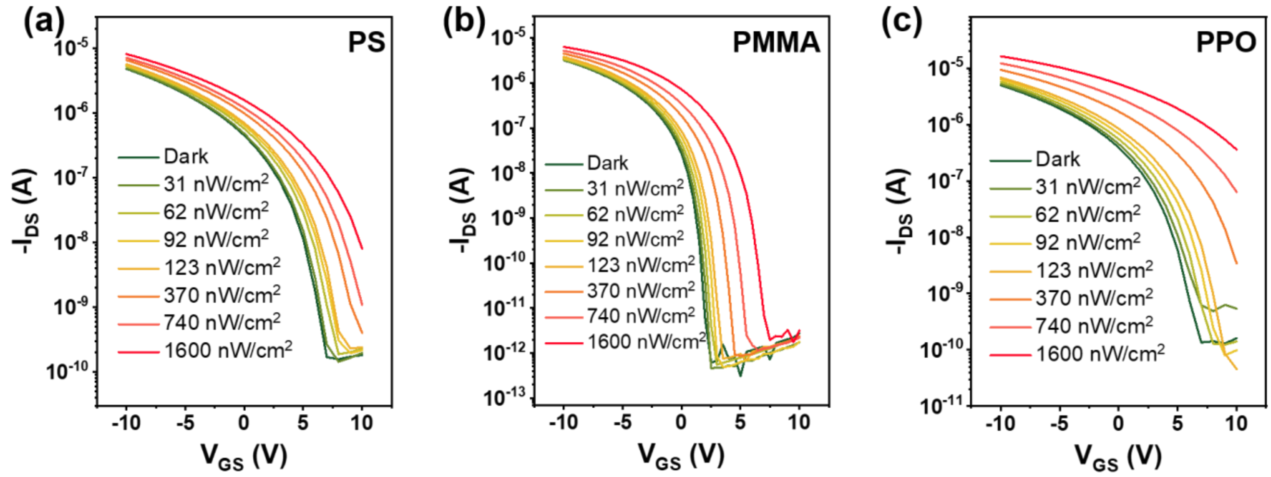

Figure S9. The transfer curves of the UV-sensitive OPTs based on (a) PS, (b) PMMA; (c) PPO.

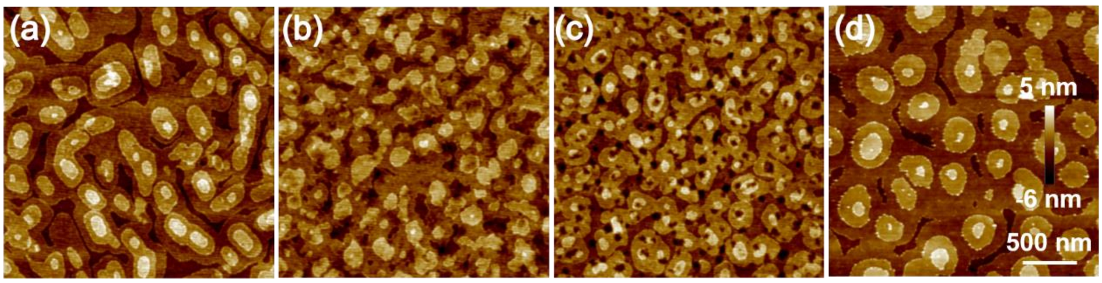

Figure S10. 3 μm×3 μm AFM images of BTBTT6-syn films on different dielectric surfaces, (a) Bare SiO_2; (b) SiO_2/PS; (c) SiO_2/PMMA; (d) SiO_2/PPO.

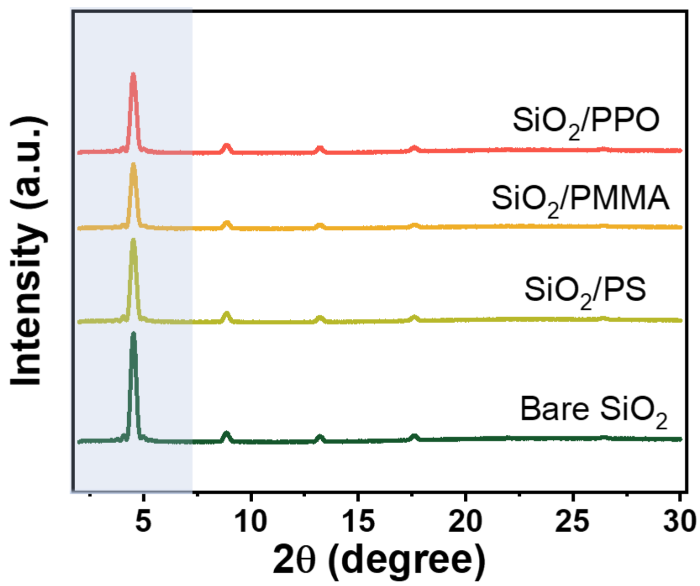

Figure S11. XRD patterns of BTBTT6-syn films vacuum deposited on bare SiO_2, SiO_2/PS, SiO_2/PMMA, SiO_2/PPO.

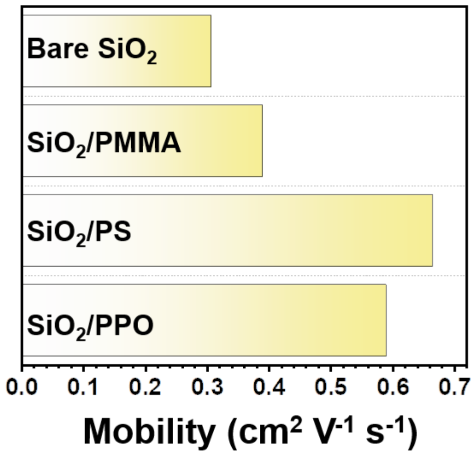

Figure S12. Mobility with bare SiO_2, SiO_2/PMMA, SiO_2/PS, SiO_2/PPO.

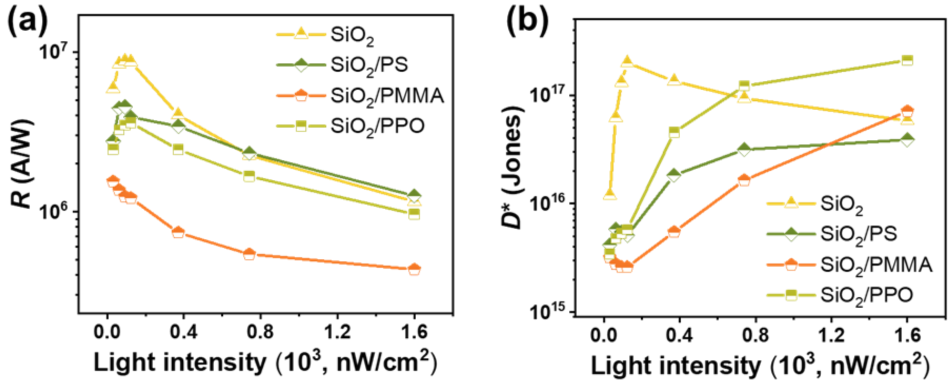

Figure S13. (a) R in different interface as a function of illumination intensity. (b) D^* in different interface as a function of illumination intensity.

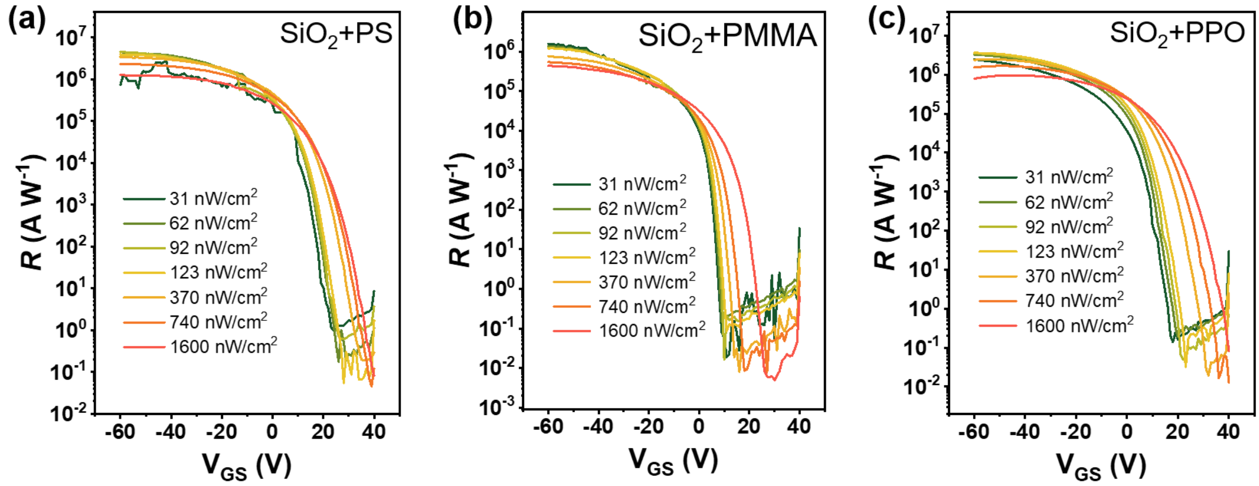

Figure S14. The photoresponsivity (R) of the phototransistor based on (a) SiO_2/PS; (b) SiO_2/PMMA; (c) SiO_2/PPO.

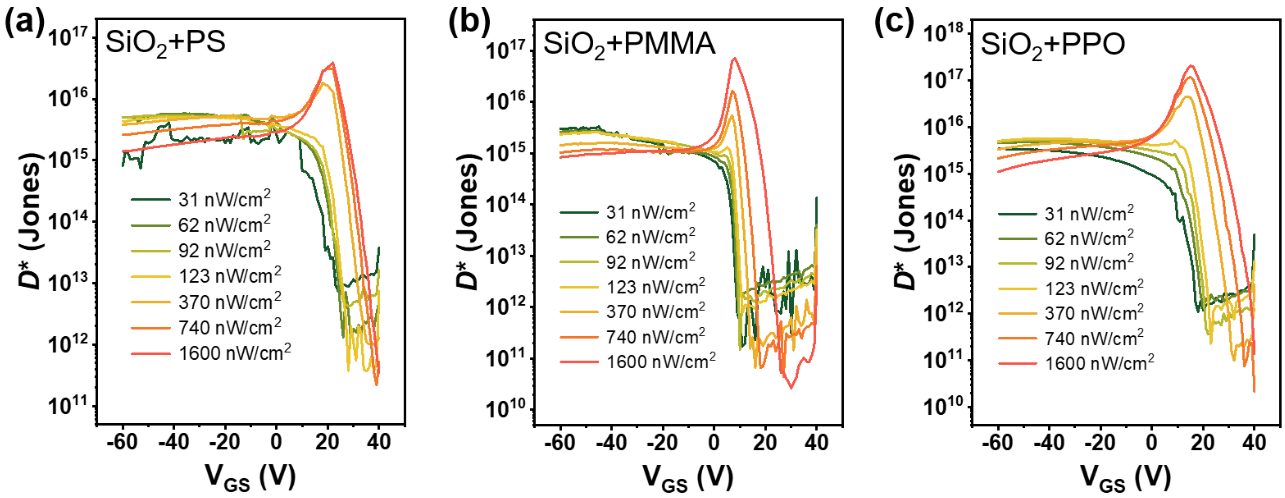

Figure S15. The detectivity (D^{*}) of the phototransistor based on (a) SiO_2/PS; (b) SiO_2/PMMA; (c) SiO_2/PPO.

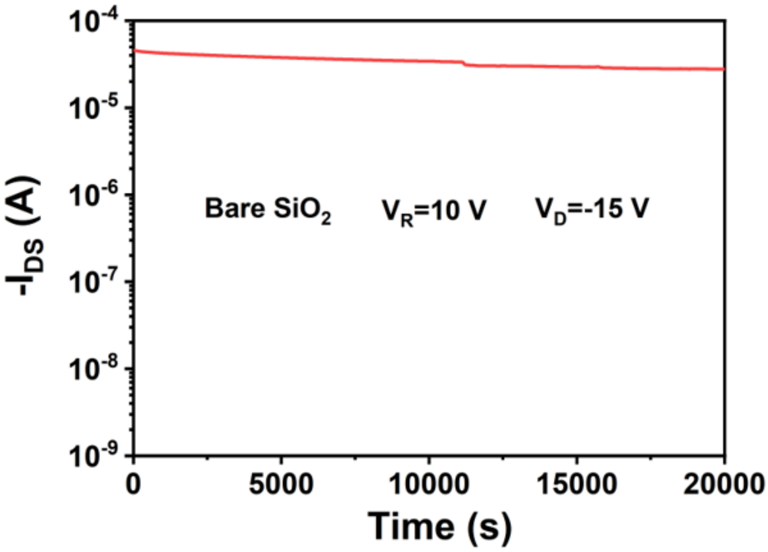

Figure S16. The retention property of the bare SiO_2 device.

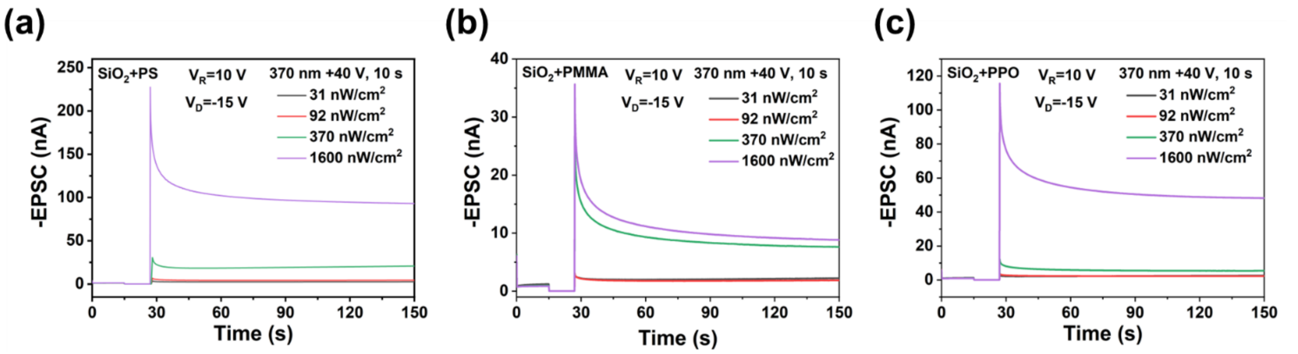

Figure S17. EPSC of the devices with different buffer layers trigged by various illumination intensities (a) SiO_2/PS; (b) SiO_2/PMMA; (c) SiO_2/PPO.

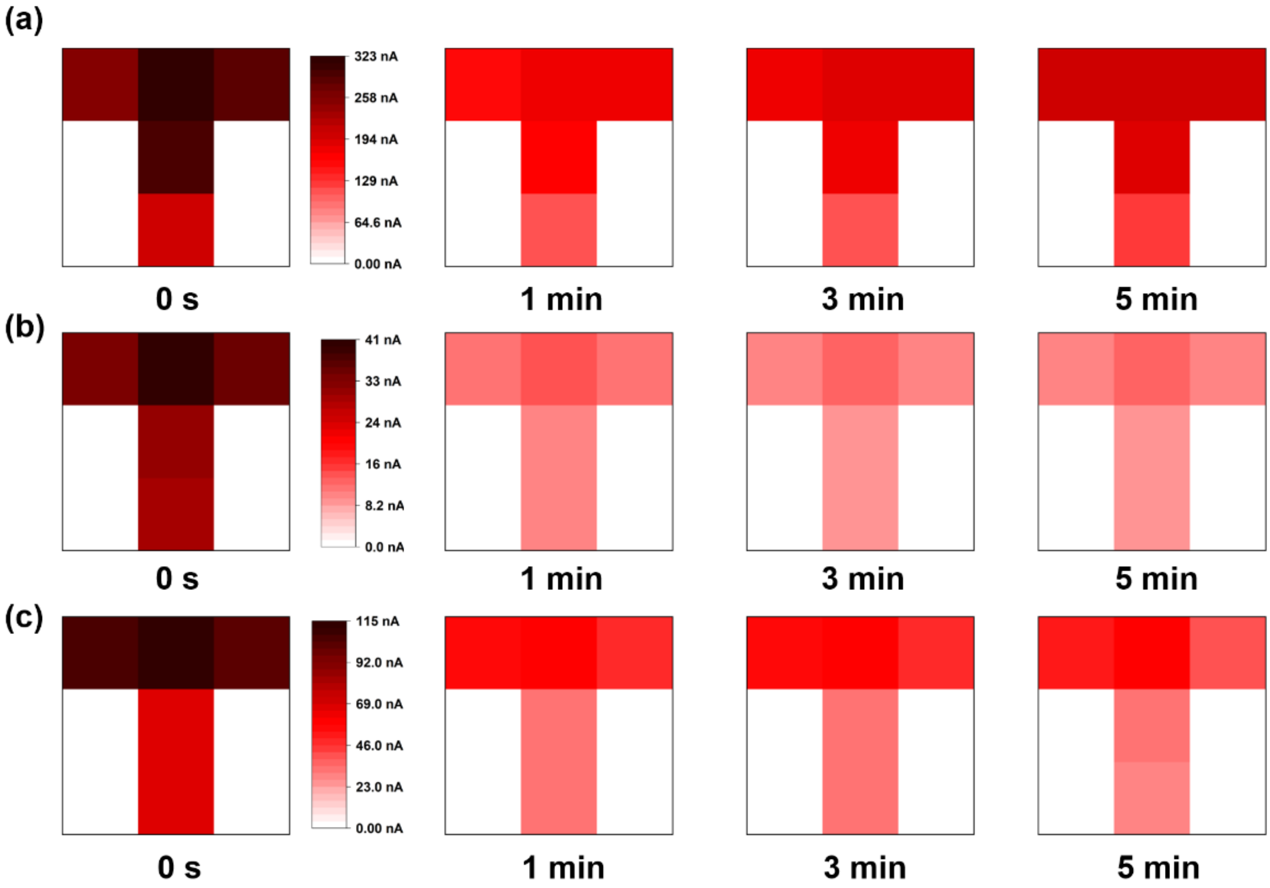

Figure S18. The image memorization property of the devices with different buffer layers (a) SiO_2/PS; (b) SiO_2/PMMA; (c) SiO_2/PPO.

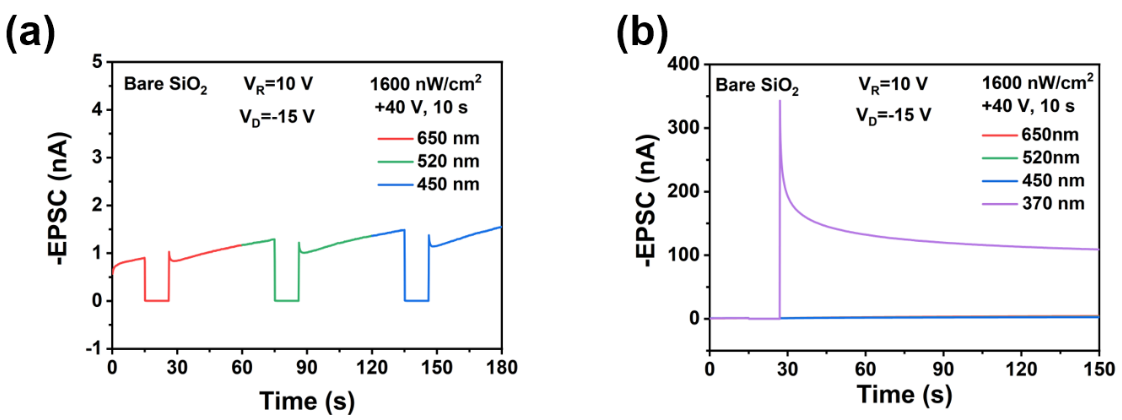

Figure S19. EPSC of bare SiO_2 device trigged by various wavelengths illumination (a) RGB; (b) RGB and UV.

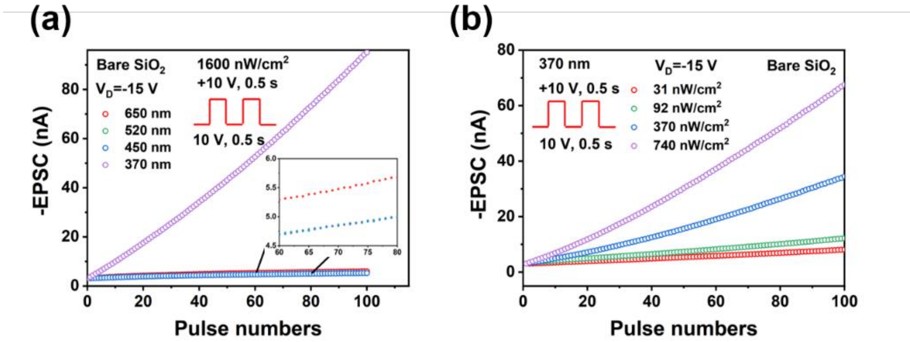

Figure S20. LTP of bare SiO_2 device trigged by various (a) wavelengths; (b) illumination intensities.

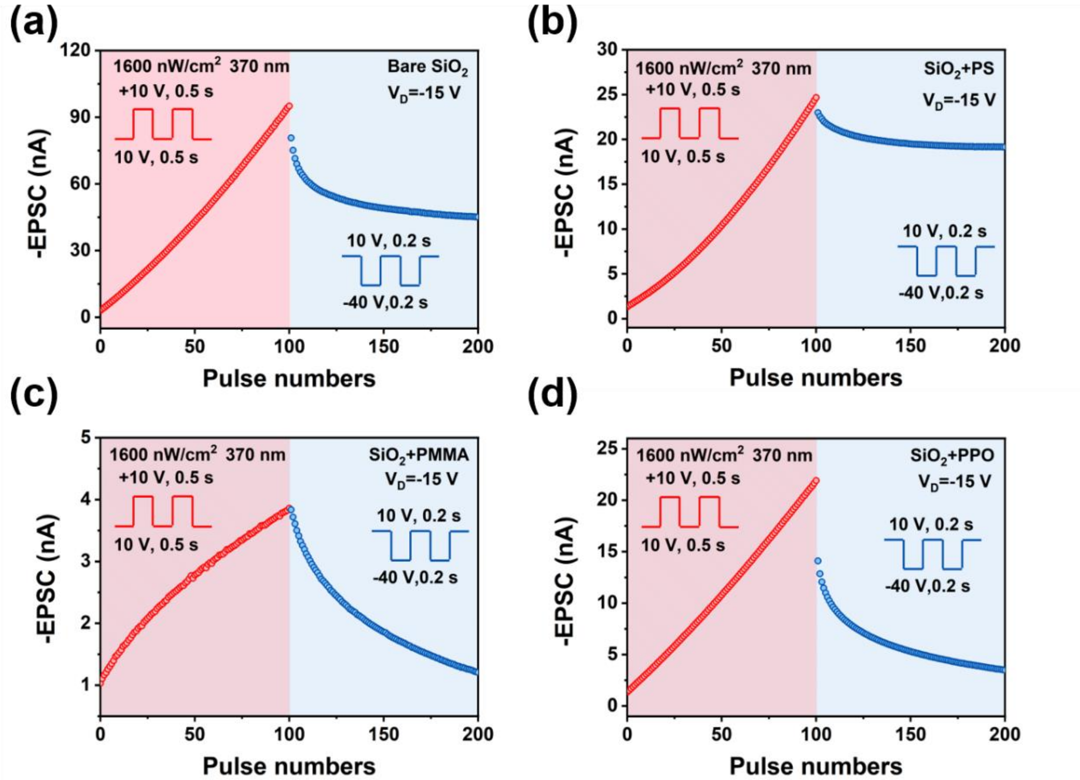

Figure S21. LTP/LTD curves of the devices with different buffer layers (a) bare SiO_2; (b) SiO_2/PS; (c) SiO_2/PMMA; (d) SiO_2/PPO.

Table S1. Comparison of current work with representative phototransistors.

Response material	Detection limit (mw cm^{-2})	Wavelength (nm)	P_{Max}	R_{Max} (A W^{-1})	D^*_{Max} (Jones)	Growth mode	Ref.
DFD+TMTES-P	0.078	365	5.3×10^3	5.3×10^3	2.78×10^{14}	cocrystal	1
C8-BTBT+$AgBiS_2$ QD	0.0038	365	1.5×10^3	20	4×10^{13}	hybrid films (spin-coating)	2
BBDTE	0.037	380	10^5	9821	/	single crystal	3
BBDTY			4429	9336	/	thin films	
BOPAnt	0.11	350	4.34×10^5	3100	/	single crystal	4
C8-BTBT + PLA	0.02	365	1×10^5	56	/	films (spin-coating)	5
DTTQ+ $CsPbBr_3$ QD	0.0005	365	1.8×10^4	7.1×10^5	3.6×10^{13}	films (solution-shearing)	6
1,6-DTEP	0.0002	370	1.60×10^5	2.86×10^6	1.49×10^{18}	single crystal	7
2,7-DTEP			4.35×10^3	1.04×10^5	5.28×10^{16}		
$PC_{61}BM$	0.007	315-400	9×10^3	3×10^3	1.3×10^{13}	films (spin-coating)	8
NDI-C_6+C_8-BTBT	0.3	365	50	1.78	/	organic crystalline	9
2-An-BTBT	0.0177	380	1576	7136	/	single crystal	10
TPA-An	0.0002	370	1.03×10^3	7.19×10^5	1.40×10^{16}	single crystal	11
TBA-An			3.45×10^4	1.50×10^5	1.60×10^{17}		
C8-BTBT+ polythioether	4.0	350	1.0×10^5	2.5	6.3×10^{14}	films (spin-coating)	12
NDI-PM	0.001	365	2.0×10^5	1980	1.8×10^{14}	thin-films	13
BTBTT6-syn (Bare SiO_2)	3.1×10^{-5}	370	1.2×10^4	9×10^6	2×10^{17}	thin-films	This work
BTBTT6-syn (SiO_2/PS)	3.1×10^{-5}	370	1.64×10^5	4.5×10^6	3.9×10^{16}		

BTBTT6-syn (SiO_2/PMMA)	3.1×10^{-5}	370	3.47×10^{5}	1.2×10^{6}	7.1×10^{16}	thin-films	This work
BTBTT6-syn (SiO_2/PPO)	3.1×10^{-5}	370	8×10^{5}	3.6×10^{6}	2.1×10^{17}		

Supplementary Note 1

In convolution processing, a matrix of weight values used to perform a weighted average operation is designed and called convolution kernel. Convolution kernel can be used in the convolutional neural network to extract local features after training[14]. In this case, the OPT array is used as a convolution kernel for extracting UV feature. It is worth noting that such convolution kernel is used to perform a weighted average operation on the RGB and UV values of a single pixel. Therefore, a device array with the same size as the input image can realize the whole convolution processing in one step. A weight function based on device characteristics is defined and would be used in subsequent computer simulation. Since the device exhibits wavelength-dependent tunable synaptic plasticity, the result of convolution processing based on the device characteristics is the sum of the responses to light of different wavelengths. The equation describing the convolution operation is as follows:

$$f_{Output} = \frac{f_R(\mathrm{R}) + f_G(\mathrm{G}) + f_B(\mathrm{B}) + f_{UV}(\mathrm{UV})}{4}$$

where f_{Output} is the output value obtained by weighting and averaging the RGB and UV values of a pixel. $f_R(R)$, $f_G(G)$, $f_B(B)$ and $f_{UV}(UV)$ are the weight functions of the R, G, B and UV values in the image, respectively. Corresponding to the device characteristics, the output is the sum of the current change in response to light spikes at 650 nm, 520 nm, 450 nm and 370 nm. Under the irradiation of different light wavelengths. As shown in Figure S19 and S20, the EPSC and weight update values obtained under the illumination of RGB light are much lower than that of UV light, that is, the information given by the UV light is the dominate information. It is assumed that the output gray value of every pixels of RGB in the image are approximated by the ratio of the weight values between RGB and UV.

To demonstrate the advantages in image recognition with the pre-processing feature of focusing on UV information, the comparations of image recognition accuracy under different conditions are needed. In this case, three test datasets are used. The first dataset is the initial MNIST test dataset, including 10,000 test images (where each image is 20 × 20 pixels). RGB mode are used to store information with different colors in the images, and a separate value is introduced to storage the UV information. For the second dataset, the Gaussian noise is added into the RGB values and the UV information is not changed, so that the images with fuzzy visible light information and clear UV information are obtained. Then, the third dataset is gained with the second dataset pre-processed by the simulated convolution kernel array, in which the UV information is strengthened and the visible light information is weakened. So, the third dataset simulated the situation that vision system focusing on the UV information.

The image recognition process is performed using a three-layer ANN (400 input neurons, 100 hidden neurons and 10 output neurons). The activation functions of the hidden layer and output layer are Relu and Softmax, respectively. The synaptic weight (w) in the ANN are determined by a pair of normalized conductance values, $w = \frac{G^{+}-G^{-}}{G_{max}}$.

The recognition accuracy is calculated using the experimental LTP/LTD data (Figure S21), the recognition accuracy of each dataset is calculated by:

$$Accuracy\ (\%) = \frac{n}{\mathrm{N}} \times 100\%$$

where Accuracy and n denote the recognition accuracy and the number of correctly identified images, respectively. N is the total number of images in the dataset, equal to 10,000.

References

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