Supporting Information

Titanium oxide-based Optoelectronic Synapses with Visual Memory Synergistically Adjusted by Internal Emotions and Ambient Illumination

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The absorbance spectrum of the TiO_{2-x} thin film was recorded in the range of 300-1000 nm, as shown in Fig. S1. The optical band gap (Eg) is estimated by the Tauc plot.

$$(\alpha h v)^{1/n} = B(Eg - hv) \quad (1)$$

where α is the absorption coefficient, h is the Planck's constant, ν is the frequency and B is a constant. The exponent n is directly related to the semiconductor type. The optical band gap of TiO_{2-x} is estimated to be 3.56eV which exhibits band gap direct transitions (n=1/2) [1,2]. The value is consistent with data in other reports [3].

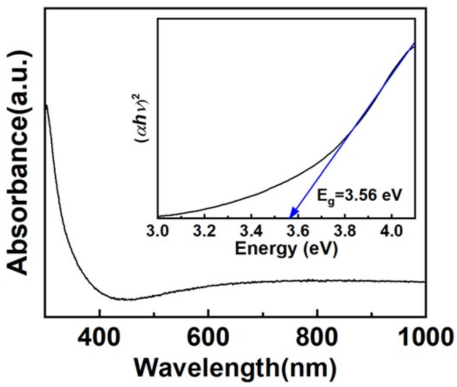

Fig. S1 Absorbance spectra of the TiO_{2-x} based film. Inset: Band gap width fitted according to the Taut plot.

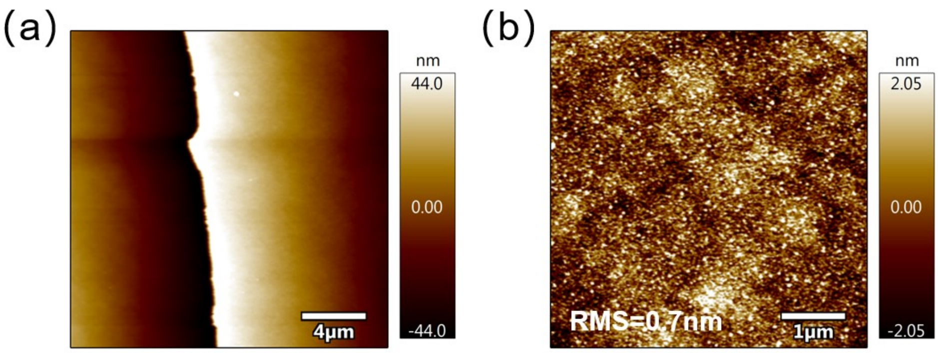

Fig. S2 The step height (a) and surface (b) image of the as-prepared TiO_{2-x} film measured by AFM.

The XPS survey spectrum shown in Fig. S3 reveals that the samples mainly contain Ti, O, and C element.

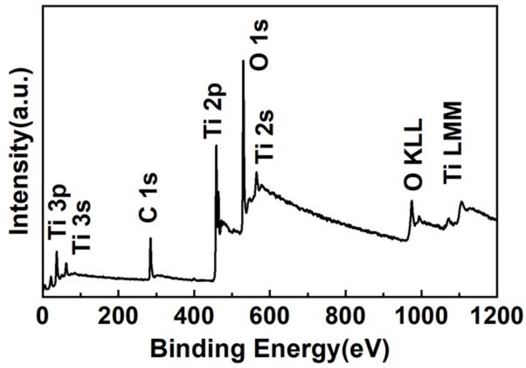

Fig. S3 XPS spectra of survey spectrum

X-ray diffraction images of the surface and deep layers of TiO_{2-x} films show that the films contain TiO, TiO_2, Ti_2O_3, Ti_7O_{13}, Ti_3O_5 and $TiO_{0.7207}$ [4-7]. This situation indicates that there are many defect states on the surface and deep layer of TiO_{2-x} film.

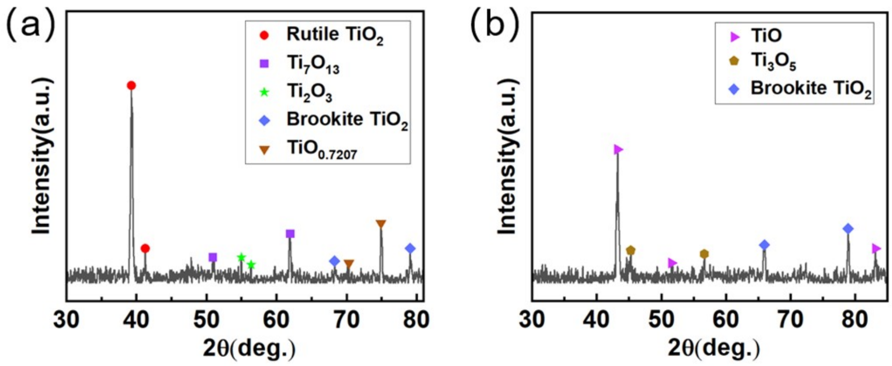

Fig. S4 X-ray diffraction images of the surface (a) and deep layers (b) of TiO_{2-x} film.

As shown in Fig. S5, the decayed EPSC curve can be fitted with the Kohlrausch stretched-exponential function shown below [8,9]:

$$I_t = \Delta I \times exp[-(t-\tau)^{\beta}] + I_{\infty} \quad (2)$$

where τ and β is the relaxation time and the stretch index ranged between 0 and 1, respectively, while I_{∞} is the resting current of 1.15 nA. The τ value is estimated to be ~15 s.

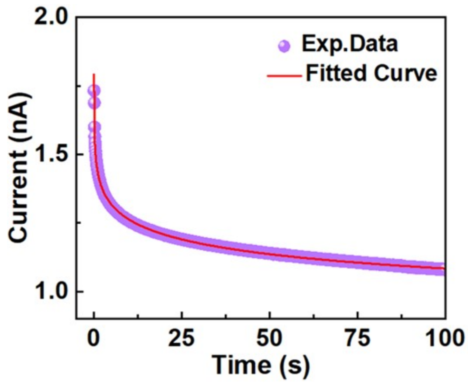

Fig. S5 The decayed EPSC curve fitted with a stretched exponential function.

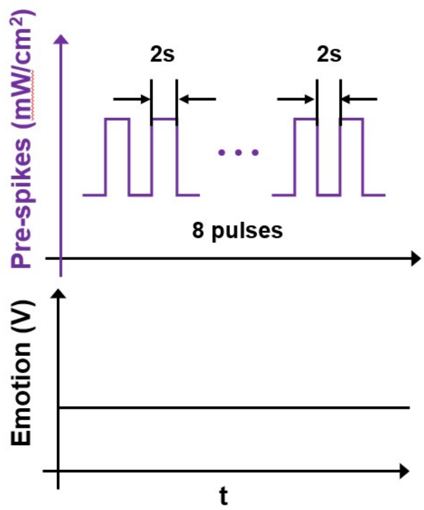

Fig. S6 Visual event memory process with different internal emotion states. The internal emotion is triggered by 0.5 V and 0.7 V and 1.0 V, respectively. The same visual memory event is fixed to be triggered by the 365 nm light pulses with the intensity of 3.0 mW/cm^2, duration time of 2 s and interval time of 2 s.

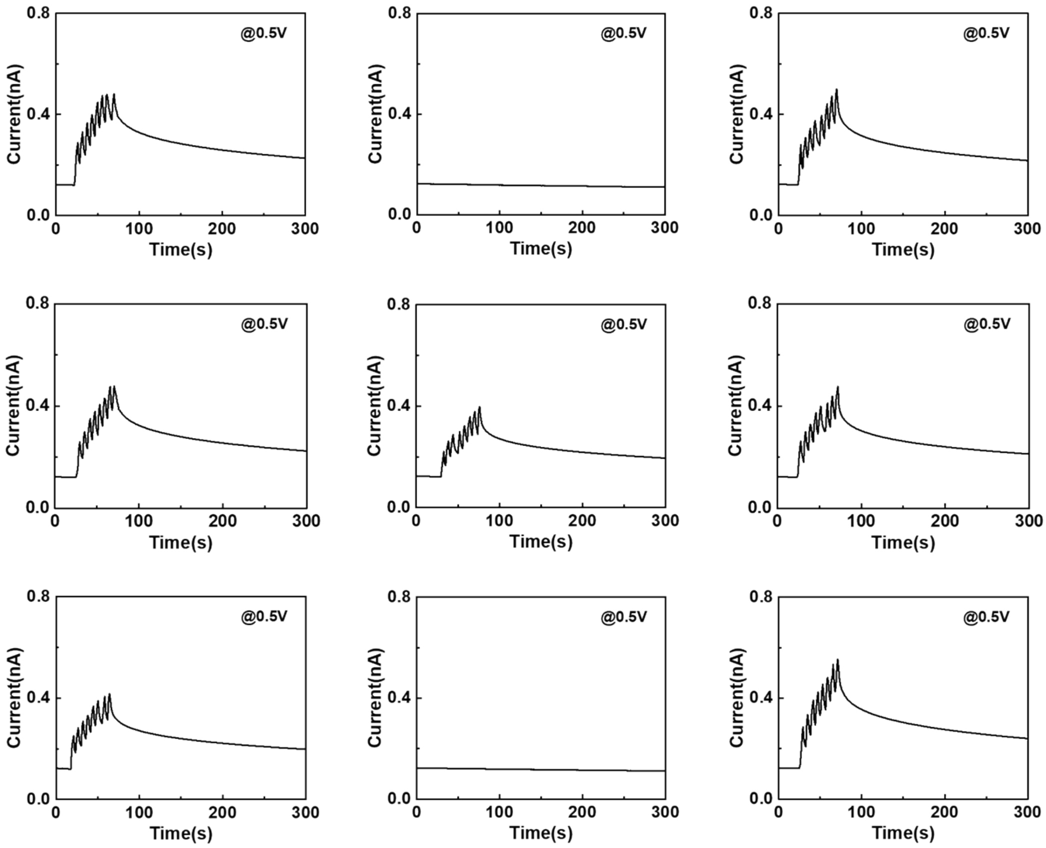

Fig. S7 The current response under light pre-spikes with bias at 0.5 V.

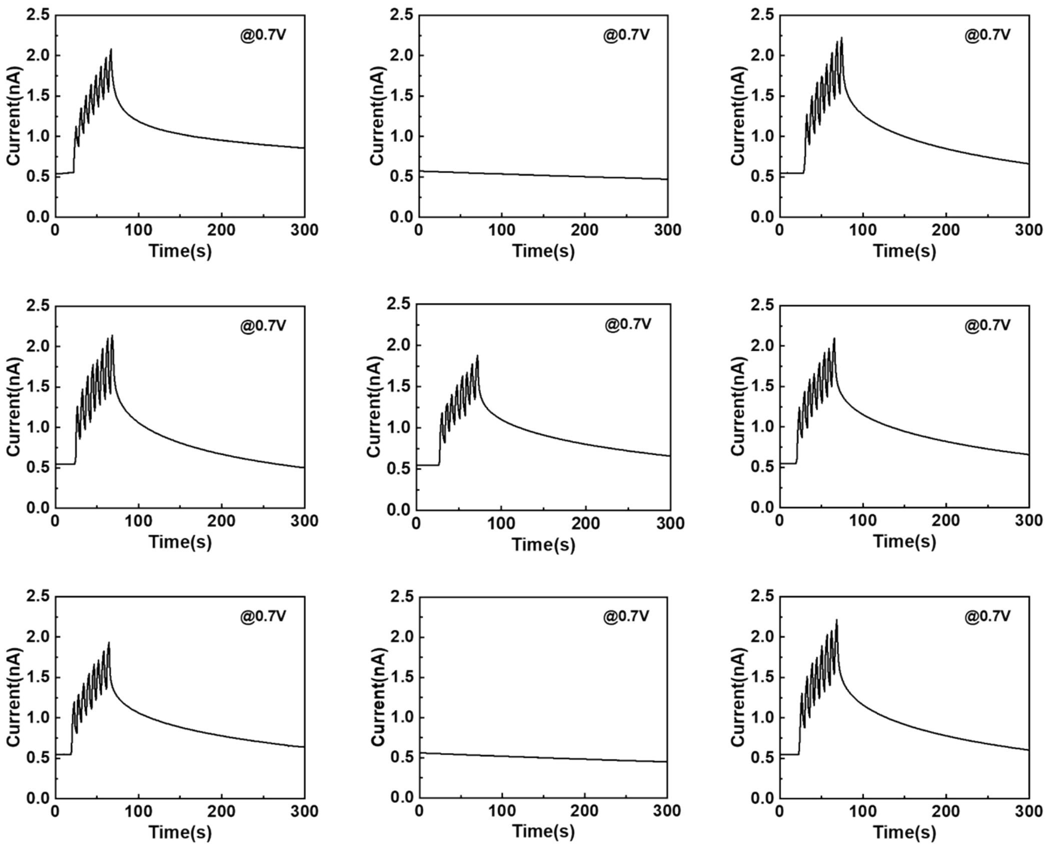

Fig. S8 The current response under light pre-spikes with bias at 0.7 V.

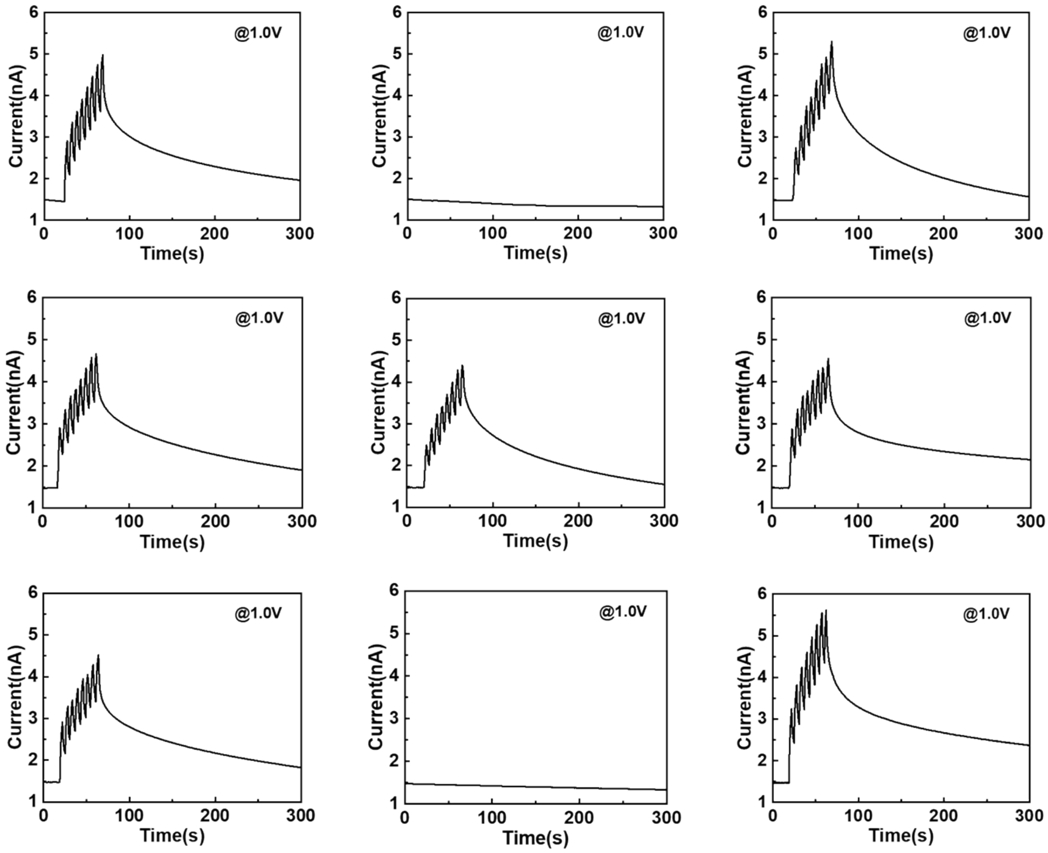

Fig. S9 The current response under light pre-spikes with bias at 1.0 V.

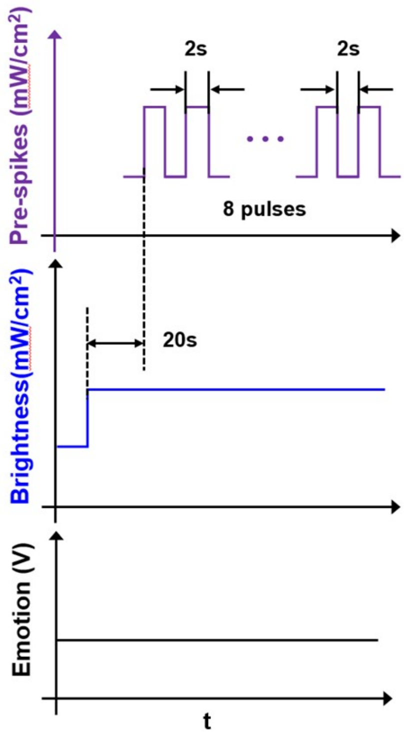

Fig. S10 Visual event memory process with different ambient brightness. The intensities of ambient brightness are 1.2 mW/cm^2, 3.0 mW/cm^2 and 4.0 mW/cm^2, respectively. The emotion is fixed at 1.0 V (bias).

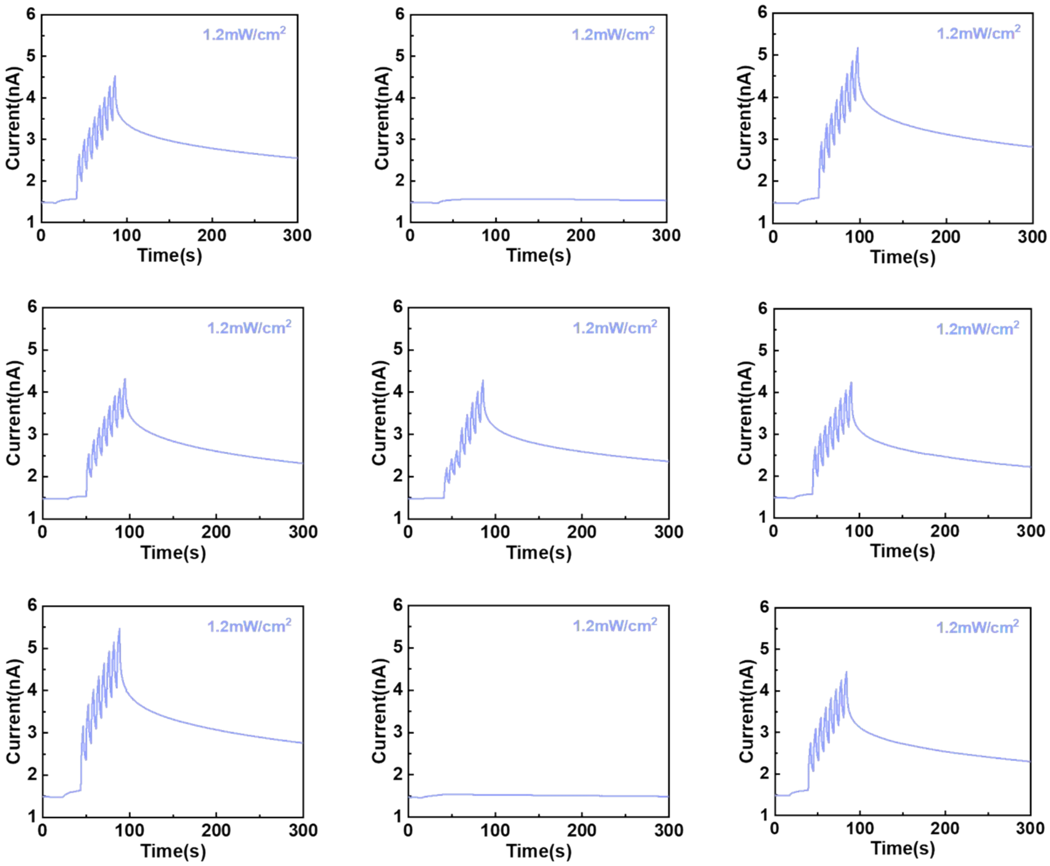

Fig. S11 The current response triggered by light pulses with ambient brightness of 1.2 mW/cm^2 light intensity.

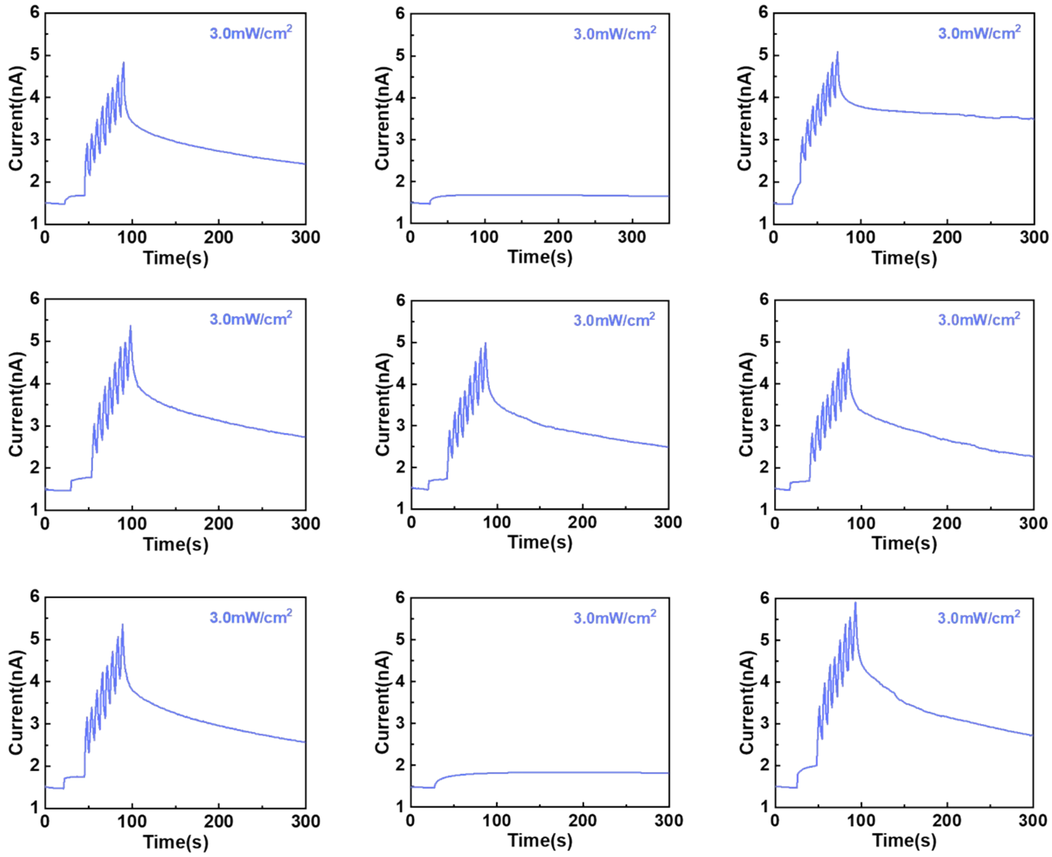

Fig. S12 The current response triggered by light pulses with ambient brightness of 3.0 mW/cm^2 light intensity.

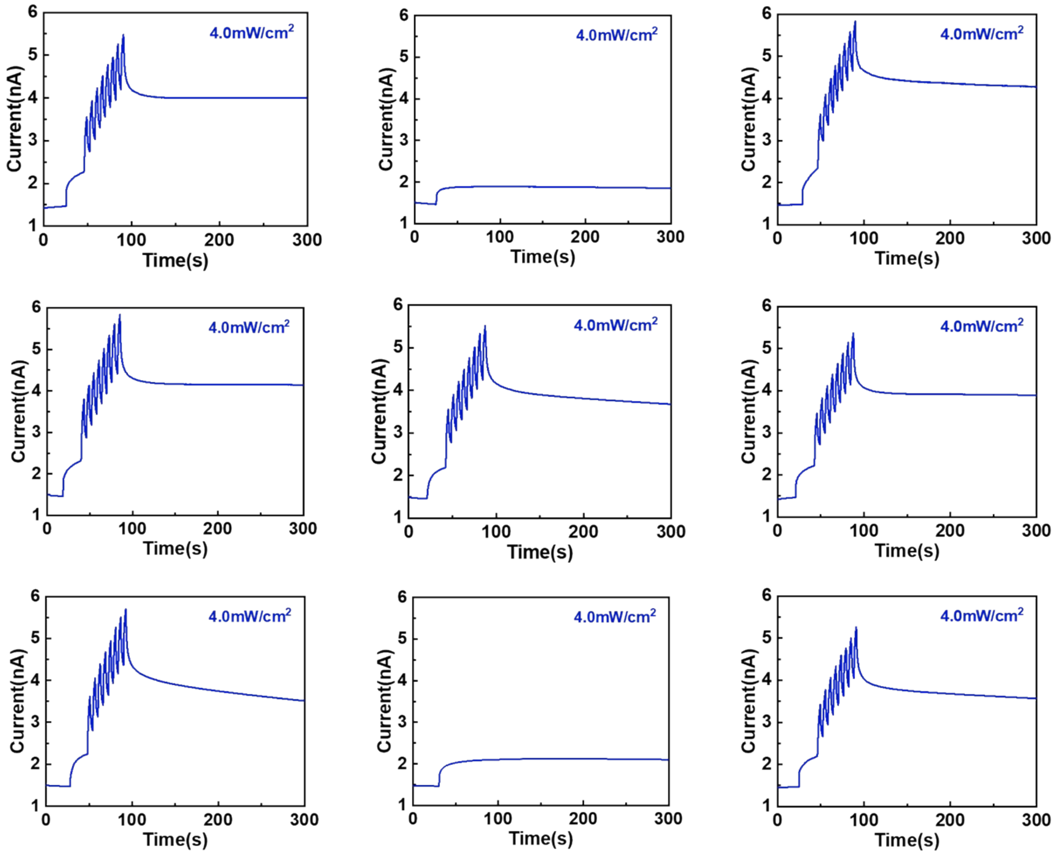

Fig. S13 The current response triggered by light pulses with ambient brightness of 4.0 mW/cm^2 light intensity.

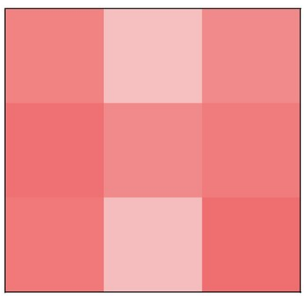

Fig. S14 The excellent visual memory with decay time at 500 s with 4.0 mW/cm^2 brightness of the ambient illumination.

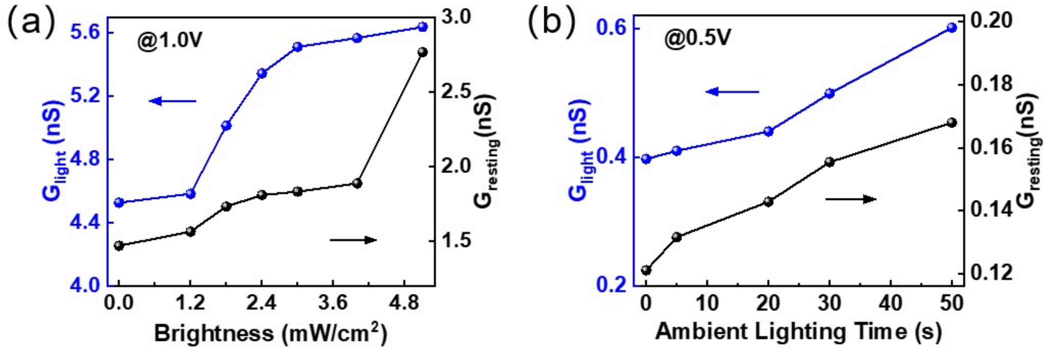

Fig. S15 (a) The compensatory effect of ambient illumination brightness on emotion and memory. (b) The function between ambient lighting time and emotion and memory.

Table S1. Comparison between previous artificial photoelectronic synapse devices and this work.

Device structure	Light source	Light intensity (mW/cm^2)	Multiple memory	Learning-forgetting-relearning	Optoelectronic synapse array	visual memory influenced by emotion and illumination
ITO/Nb:$SrTiO_3$ [10]	visible	10-30	√	√	√	-
ITO/IGZO/Al_2O_3/Al[11]	UV	0.15	√	-	-	-
ITO/MO/SiO_x/IGZO/ SiO_x/SiN_x/MO [12]	UV	500	-	-	-	-
ITO/MoS_2/TiN_xO_{2-x} [13]	UV	0.54-3.56	√	√	√	-
ITO/SnO_x/ITO [14]	visible	4-16	√	√	√	-
ITO/TiO_2/*p*-Si (This work)	visible	0.5-3.0	√	√	√	√

Symbols "√" and "–" denote demonstrated and non-demonstrated synaptic functions, respectively.

References

[1] D. Reyes-Coronado, G. Rodriguez-Gattorno, M. E. Esponosa-Pesqueira, C. Cab, R. Coss and G Oskam, *Nanotechnology,* 2008, **19**, 145605.

[2] M. D. Shang, and W. Y. Ching, *Phys. Rev. B,* 1995, **51**, 13023.

[3] J.-G. Li, T. Ishigaki and X. Sun, *J. Phys. Chem. C,* 2007, **111**, 4969.

[4] M. N. Islam, and J. Podder, *Mat. Sci. in Semicon. Proc.*, 2021, **121**, 105419.

[5] M. Xiao, K. P. Musselman, W. W. Duley, and Y. N. Zhou, *ACS Appl. Mater. Interfaces,* 2017, **9**, 4808–4817.

[6] X. Yu, Y. Li, X. Hu, D. Zhang, Y. Tao, Z. Liu, Y. He, M. A. Haque, Z. Liu, T. Wu and Q. J. Wang, *Nat. Commun.*, 2018, **9**, 4299.

[7] J. Wang, Y. Li, L. Deng, N. Wei, Y. Weng, S. Dong, D. Qi, J. Qiu, X. Chen and T. Wu, *Adv. Mater.,* 2017, **29**, 1603730.

[8] L. Zhou, J. Y. Mao, Y. Ren, J. Q. Yang, S. R. Zhang, Y. Zhou, Q. Liao, Y. Zeng, H. Shan, Z. Xu, J. Fu,Y. Wang, X. Chen, Z. Lv, S. T. Han and V. A. L. Roy, *Small*, 2018, **14**, 1800288.

[9] C. J. Wang, Y. H. Liu, L. Q. Zhu, P. Feng, Y. Shi and Q. Wan, *ACS Appl. Mater. Interfaces,* 2016, **8**, 9762.

[10] S. Gao, G. Liu, H, Yang, C. Hu, Q. Chen, G. Gong, W. Xue, X. Yi, J. Shang and R. W. Li, *ACS Nano,* 2019, **13**, 2634-2642.

[11] S. Song, M. Kim, G. Yoo, S. M. Kwon, J. S. Heo, S. K. Park and Y. H. Kim, *J. Alloys Compd.*, 2021, **857**, 158027.

[12] N. Duan, Y. Li, H. C. Chiang, J. Chen, W. Q. Pan, Y. X. Zhou, Y. C. Chien, Y. H. He, K. H. Xue, G. Liu, T. C. Chang and X. S. Miao, *Nanoscale*, 2019, **11**, 17590-17599.

[13] W. Wang, S. Gao, Y. Li, W. Yue, H. Kan, C. Zhang, Z. Lou, L. Wang and G. Shen, *Adv. Funct. Mater.*, 2021, **31**, 2101201.

[14] S. E. Ng, J. Yang, R. A. John, and N. Mathews, *Adv. Funct. Mater.,* 2021, **31**, 2100807.