Long-memory retention and self-powered ultraviolet artificial synapse realized by multi-cation metal oxide semiconductor

Supporting Information

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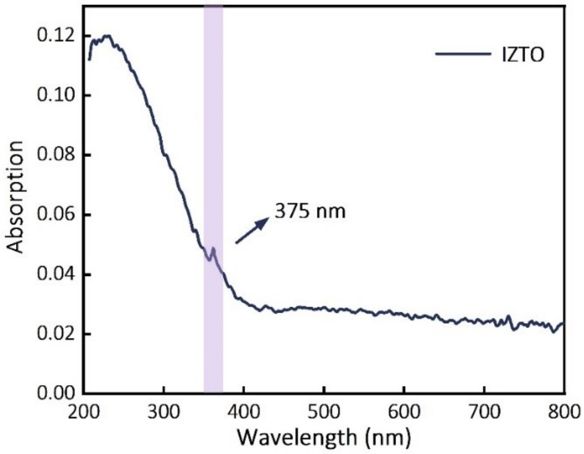

Fig. S1 UV-vis absorption spectra of IZTO-6 nanowires.

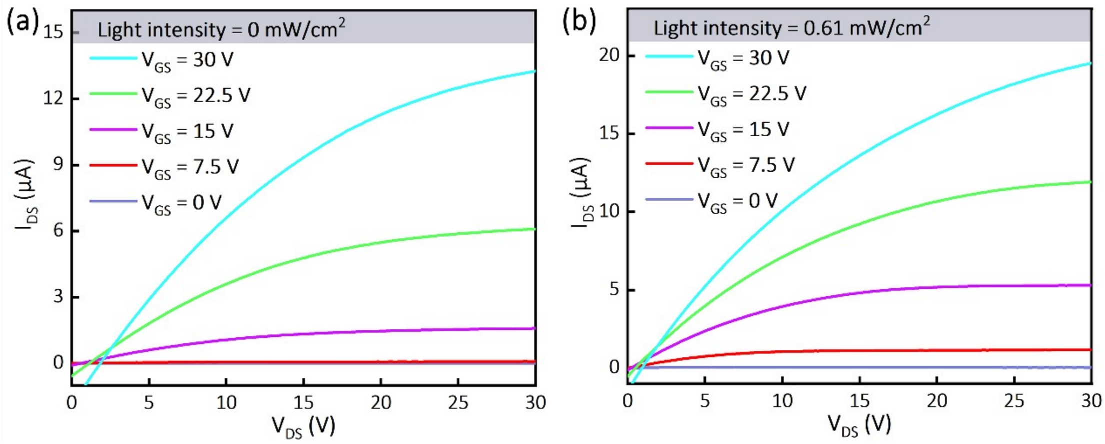

Fig. S2 (a) Output characteristic curves of IZTO-6 transistor without light. (b) Output characteristic curves of IZTO-6 transistor under illumination.

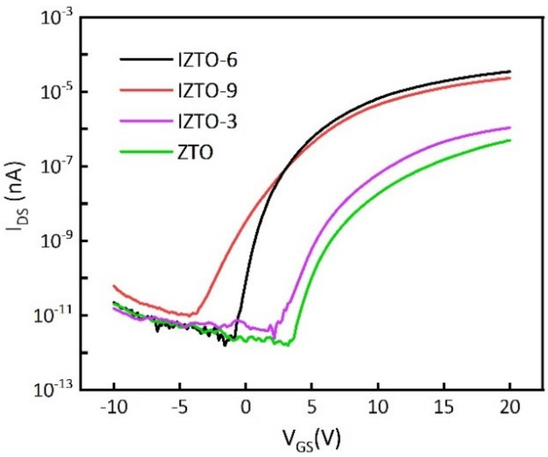

Fig. S3 The device transfer curves of different proportions.

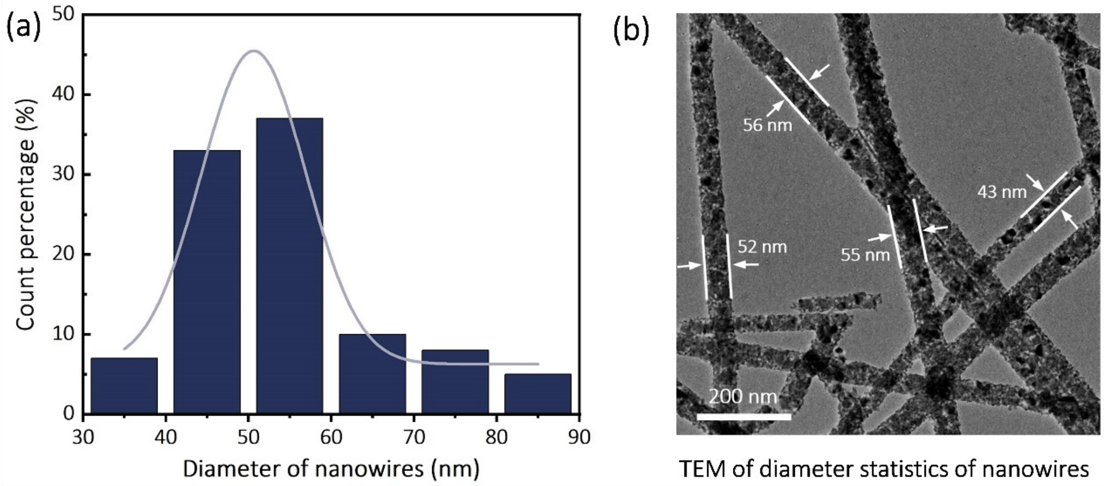

Fig. S4 (a) Diameter distribution of IZTO-6 nanowires. (b) Exemplified TEM images of measured diameter of aligned IZTO-6 nanowires.

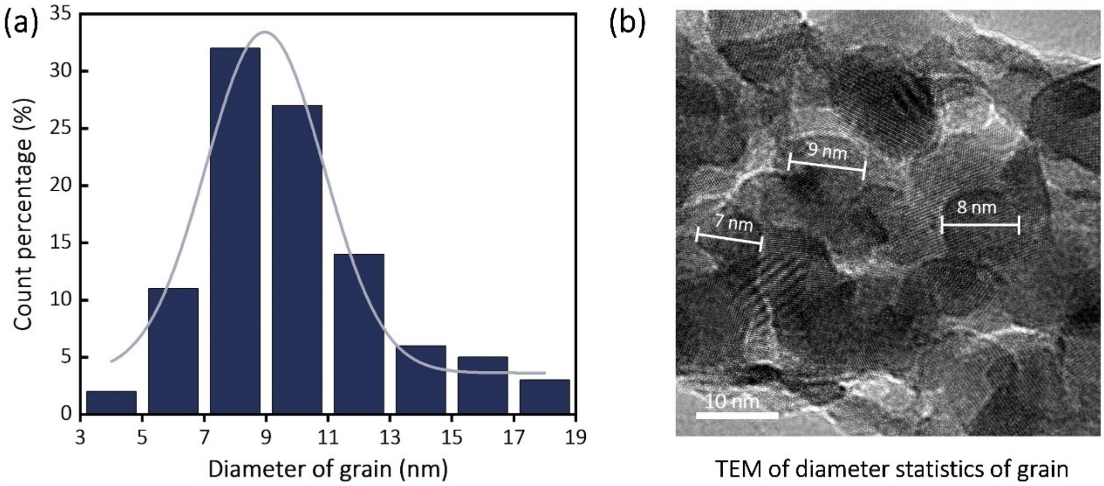

Fig. S5 (a) Diameter distribution of IZTO-6 grain. (b) Exemplified TEM images of measured diameter of aligned IZTO-6 grain.

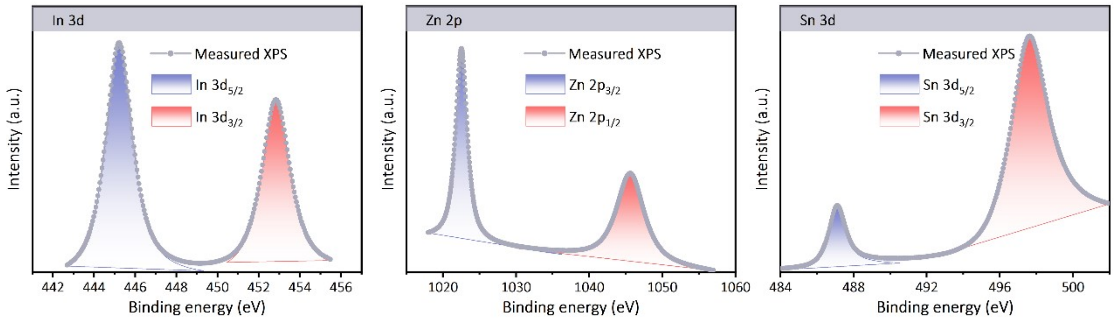

Fig. S6 XPS spectra of the IZTO-6 nanowire. From left to right: In 3d, Zn 2p, and Sn 3d.

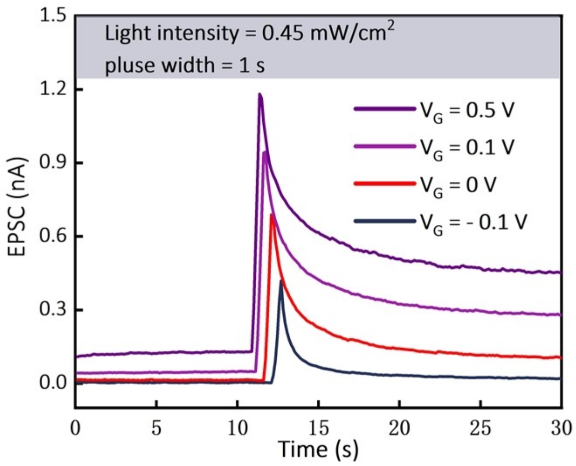

Fig. S7 EPSCs of IZTO-6 synaptic transistors with different gate voltage.

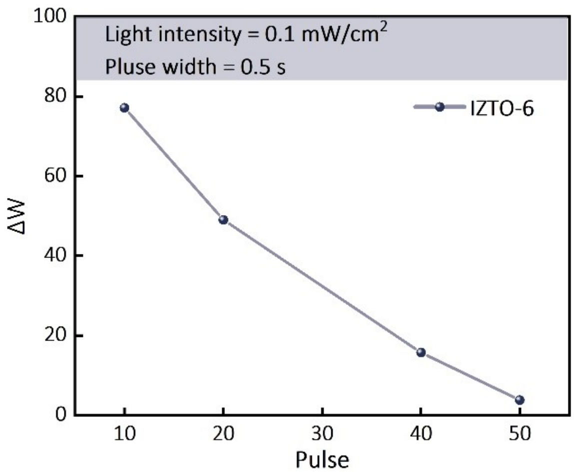

Fig. S8 The long-term weight change of the synaptic transistor based on IZTO-6 under different pulse numbers.

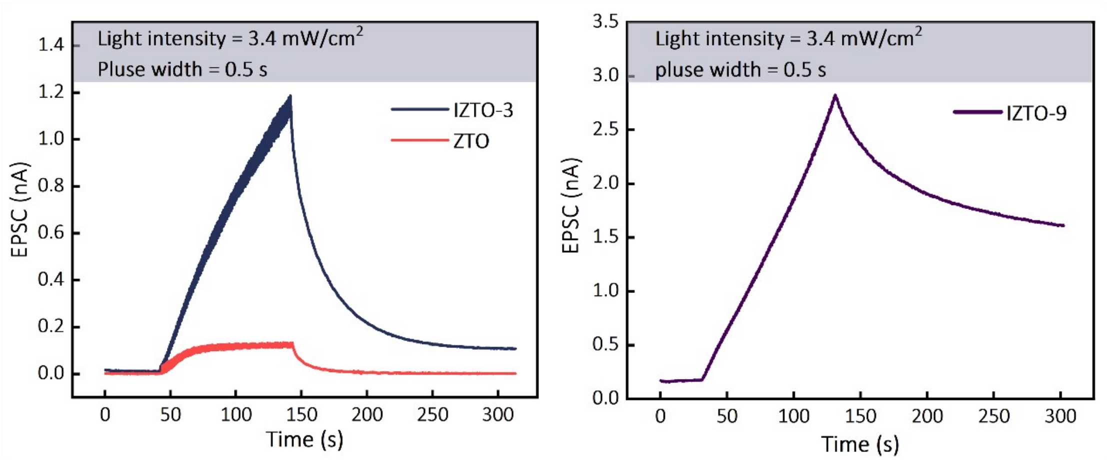

Fig. S9 Long current attenuation curves of ZTO, IZTO-3 and IZTO-9 after ultraviolet irradiation (pulse width = 0.5 s, 3.4 mW/cm^2, 100 pulse).

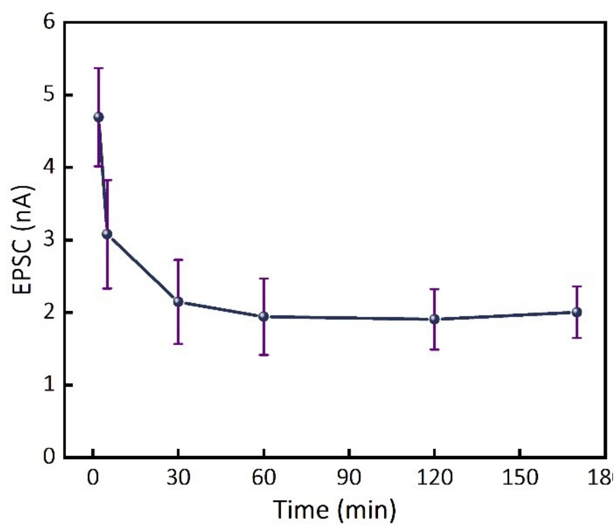

Fig. S10 Average change in LTP attenuation of IZTO-6 nanowires based optical synaptic transistor (pulse number = 100 pulse).

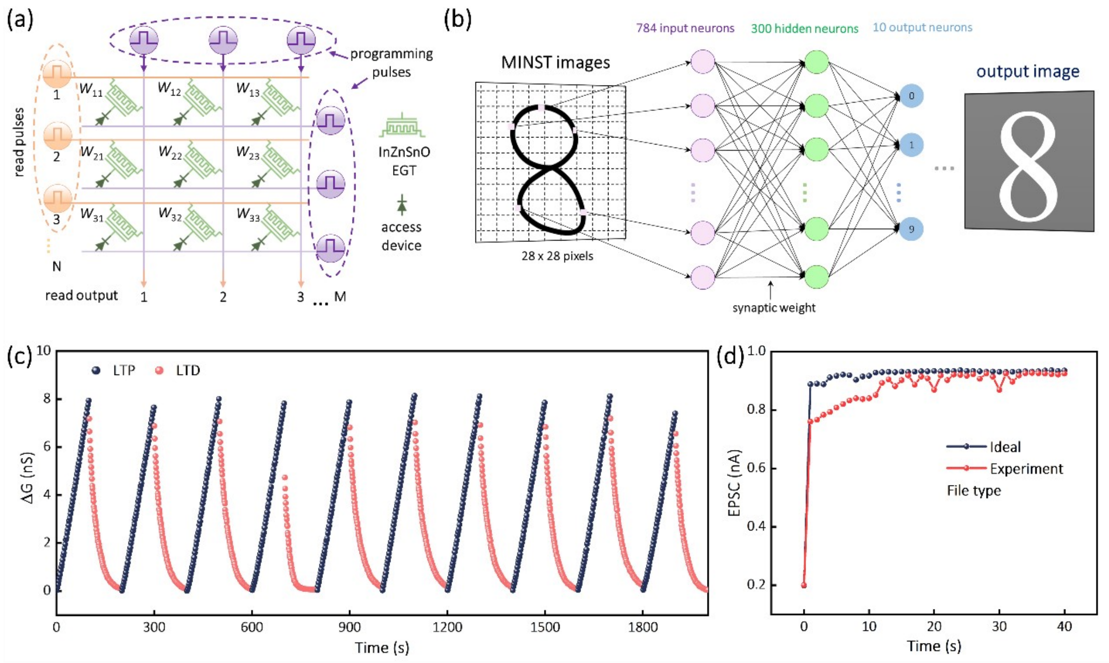

Fig. S11 (a) Corresponding circuits consisting of synapse crossbar array for matrix operations. (b) Schematic illustration of a three-layer ANN for handwritten recognition. (c) Cyclic potentiation/depression curves of circuits based on NWA synaptic transistors. (d) Recognition accuracy evolution with 40 training epochs for file type datasets.

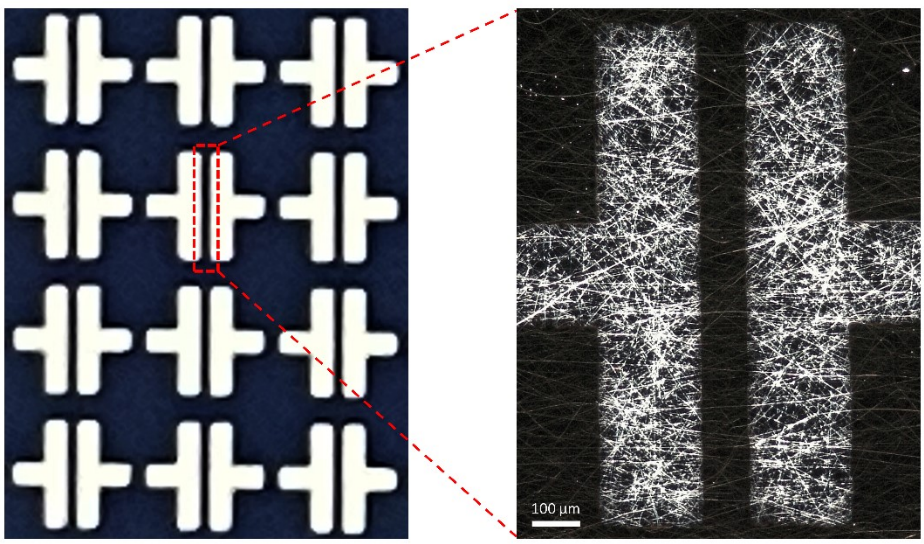

Fig. S12 Optical image of a typical array of the samples, with a zoomed-in SEM image corresponding to the area marked by the red rectangular.

Supplementary Note 1: linearity of LTP/LTD

The linearity of the LTP/LTD curve was analyzed by fitting it to the weight update equation with the following equation formula.

$$G_{n+1} = G_n + \Delta G_P = G_n + \alpha_p e^{-\beta_p \frac{G_n - G_{min}}{G_{max} - G_{min}}} \tag{1}$$

$$G_{n+1} = G_n + \Delta G_P = G_n + \alpha_d e^{-\beta_d \frac{G_{max} - G_n}{G_{max} - G_{min}}} \tag{2}$$

where G_{n+1} and G_n denote the conductance values of the synaptic device at the (n+1)st and nth applied pulses, respectively, α and β denote the step size and linearity of the conductance change, respectively.

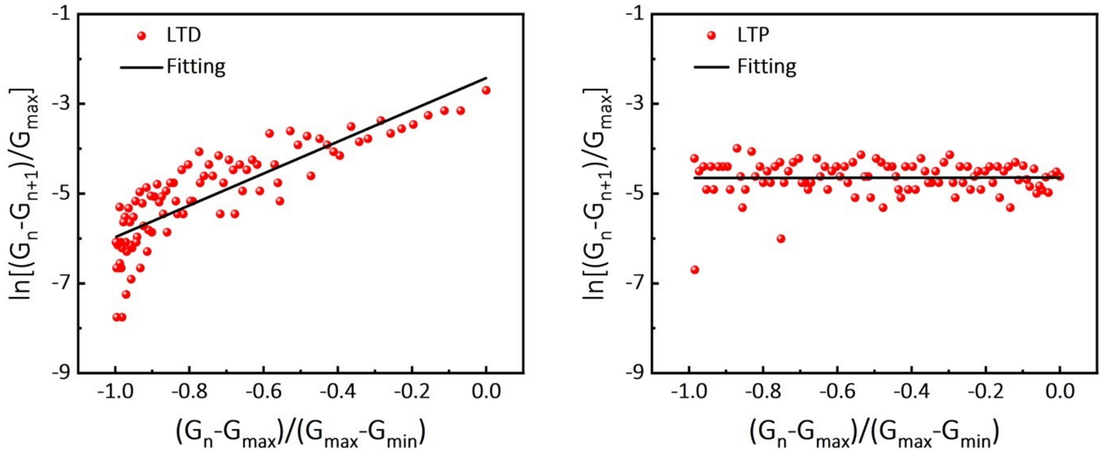

Fig. S13 Corresponding fitting of the LTP and LTD curves.

The measured LTP/LTD curves were fitted by equations, and the linearity of LTP and LTD curves were obtained as 0.01 and 3.54, respectively, and the good linearity indicated that they could be used for the image recognition function.

Supplementary Note 2: symmetricity of LTP/LTD

The symmetry is defined as the inverse of the symmetry error, which is related to the k^{th} and (2n-k) states on the LTP/LTD curve, and is shown below.

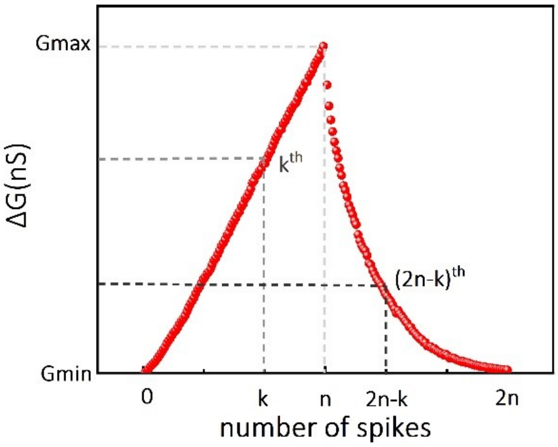

Fig. S14 Symmetricity of LTP/LTD

$$Symmetry\ error = \sum_{k=1}^{k=n} \frac{\left(G_N(K) - G_N(2n-k)\right)^2}{n} \tag{1}$$

$$= \sum_{k=1}^{k=n} \frac{\left(\left(G(k) - G_{min}\right) - \left(G(2n-k) - G_{min}\right)\right)^2}{n\left(G_{max} - G_{min}\right)^2} \tag{2}$$

$$= \sum_{k=1}^{k=n} \frac{\left(G(K) - G(2n-k)\right)^2}{n\left(G_{max} - G_{min}\right)^2} \tag{3}$$

$$G_N(k) = \frac{G(k) - G_{min}}{G_{max} - G_{min}} \tag{4}$$

In Equation (4) , G_N denotes the normalized value of conductance, G_{max} and G_{min} the maximum value of conductance and the minimum value of conductance, respectively. The symmetry error is 0.058 calculated by the above equation, which means the symmetry of LTP/LTD curve of the synaptic device is 17.11.