Electronic Supplementary Information (ESI)

Light-induced tunable threshold voltage and synaptic behavior of solution-processed indium oxide thin film transistor for logic computing and image denoising

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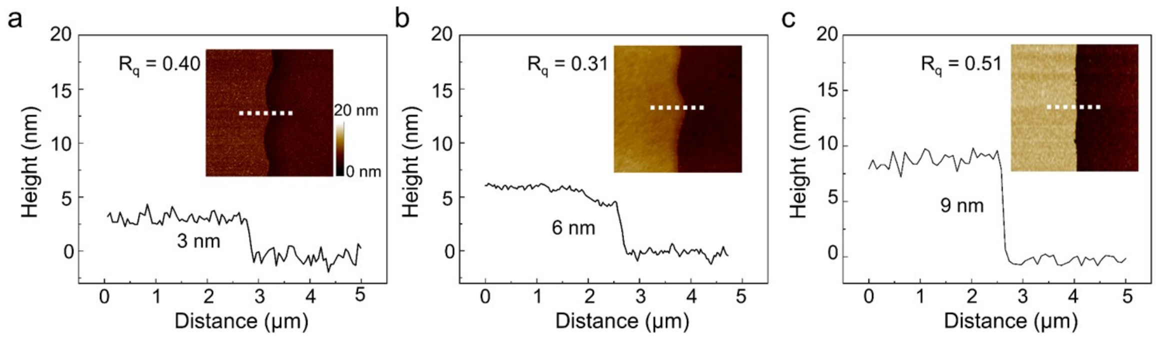

Fig. S1. The thicknesses of In_2O_3 thin films. (a) 1 layer, (b) 2 layers and (c) 3 layers. Insets are AFM images

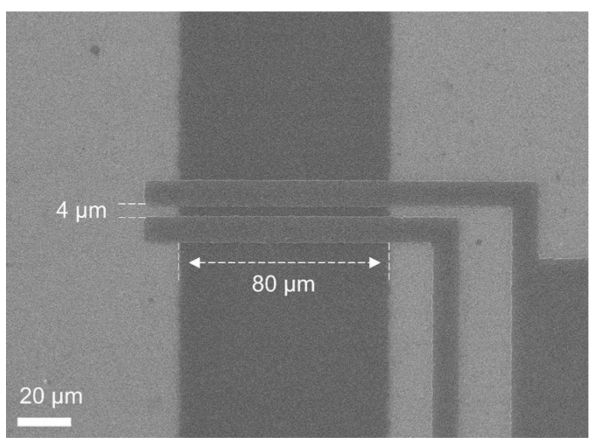

Fig. S2. The SEM image of In_2O_3 TFT.

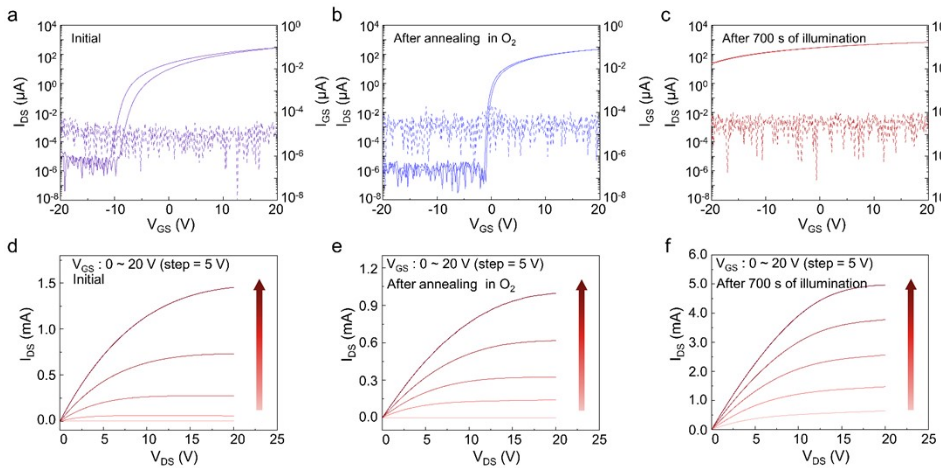

Fig. S3. Output curves of In_2O_3 TFT in (a) initial state, (b) after annealing in oxygen.

Fig. S3 shows the transfer and output curves of the In_2O_3 TFT in its initial state, after annealing in oxygen, and after 700 s of illumination. Obviously, form Fig. S3a-c, the leakage currents (I_{GS}) of the In_2O_3 TFT are significantly smaller than the source-drain currents (I_{DS}). At the same time, In_2O_3 TFTs maintain good ohmic contact in all conditions, as shown in Fig. S3d-f.

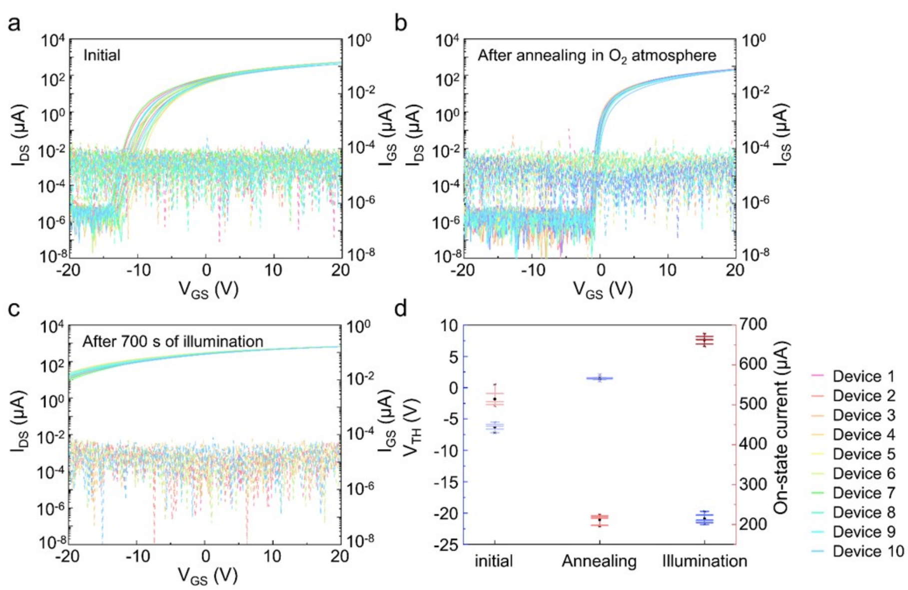

Fig. S4. Statistical data on the variation in V_{TH} of In_2O_3 TFT in the (a) initial state and (b) after annealing in oxygen and (c) after 700 s of illumination. (d) V_{TH} and on-state current statistics of In_2O_3 TFT in initial state, after annealing in O_2 and after 700 s of illumination.

As shown in the transfer curves of Fig. S4a, the transfer curves of as-fabricated In_2O_3 TFTs demonstrate the depletion operation mode with average V_{TH} of approximately -6.3 V and average on-state current of 514 μA. After annealing in O_2 atmosphere, the transfer curves of Fig. S4b show that the V_{TH} of In_2O_3 TFTs shift to 1.5 V, along with the transition from depletion operation mode to enhancement operation mode. At the same time, the on-state currents decrease to 213 μA. With the illumination times increase to 700 s, the 10 TFTs show VTH of - 21.7 V and on-state currents of 662 μA, as shown in Fig. S4c. The leakage currents of all TFTs are ~10^{-11} μA. Fig. S4d shows the V_{TH} statistics and on-state currents of 10 In_2O_3 TFTs under three conditions. Obliviously, all the solution-processed amorphous In_2O_3 TFTs show neglected deviations in V_{TH} and on-state currents under three conditions, implying the excellent reproducibility and reliability.

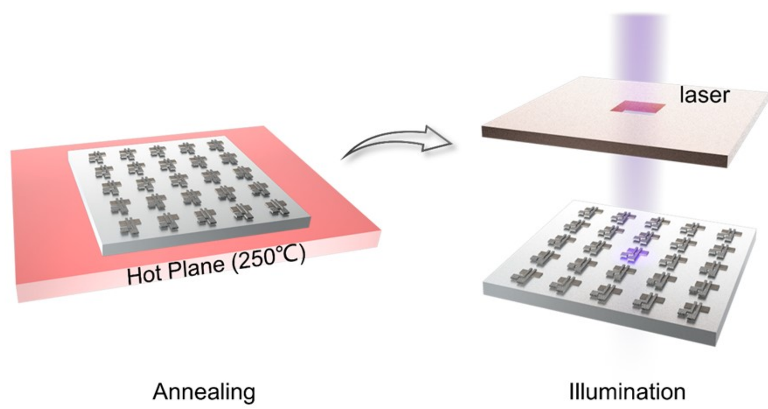

Fig. S5. Schematic diagram of annealing-illumination combined method for the precise regulation of V_{TH} of solution-processed In_2O_3 TFTs.

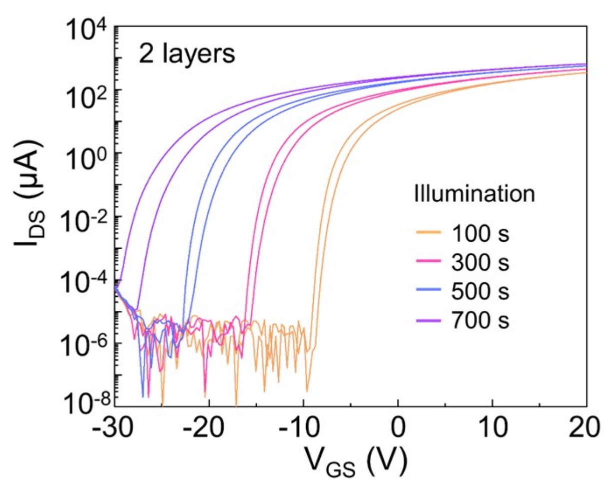

Fig. S6. Transfer curves of annealed In_2O_3 2 layers TFT under the illumination times of 100 s, 300 s, 500 s and 700 s with power intensity of 0.29 mW/mm^2.

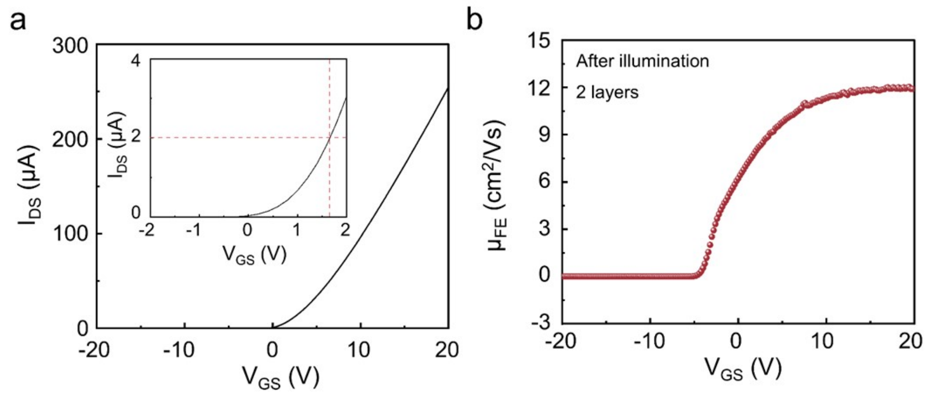

Fig. S7. Extraction methods of threshold voltage and field-effect peak mobility.

In this work, the threshold voltage (V_{TH}) is determined as the gate voltage (V_{GS}) at which the I_{DS} reaches to W/L × 100 nA.[1-3] At the same time, the field-effect peak mobility (μ_{FE}) is obtained from the formula of $\mu_{FE} = Lg_m / WC_{OX}V_{DS}$, where L is channel length, g_m is maximum transconductance, W is the channel width, C_{OX} is the gate capacitance.[4]

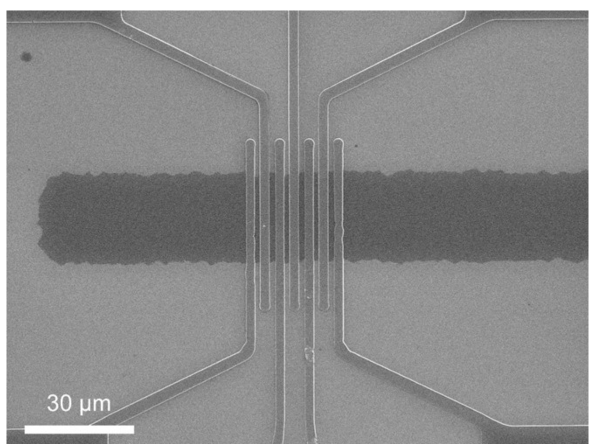

Fig. S8. SEM image of In_2O_3 top-gate TFT.

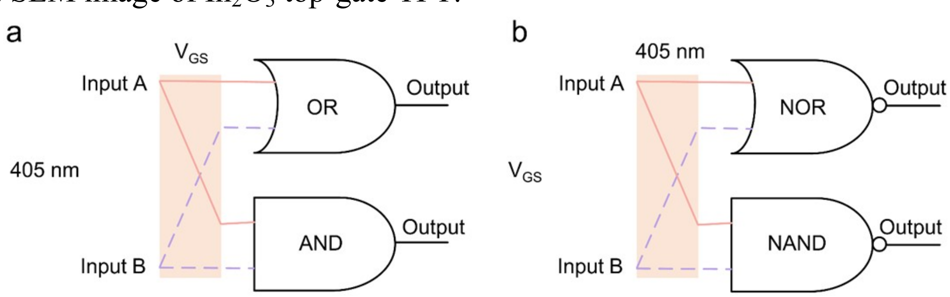

Fig. S9. Schematic operation diagram for the logic functions of (a) “OR”, “AND” (b) “NOR”, “NAND” in the optoelectronic synapse.

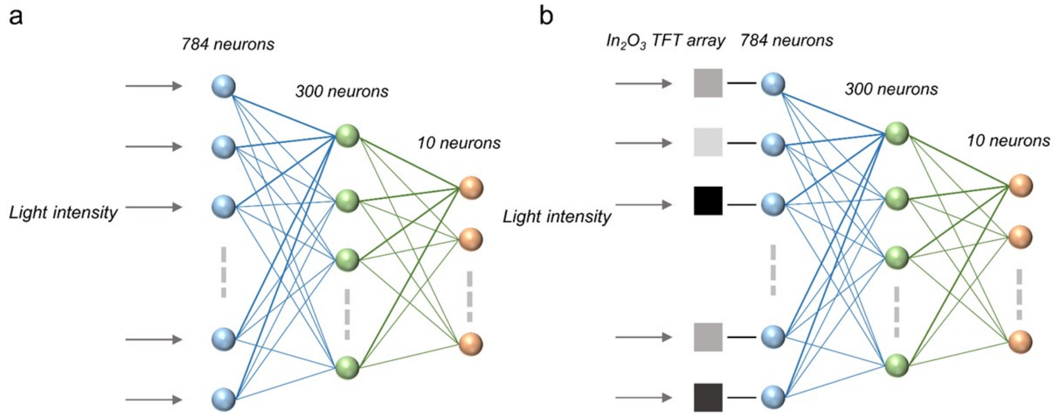

Fig. S10. (a) The structure of the three-layered artificial neural network without In_2O_3 TFTs array. (b) The structure of the three-layered artificial neural network with In_2O_3 TFTs array.

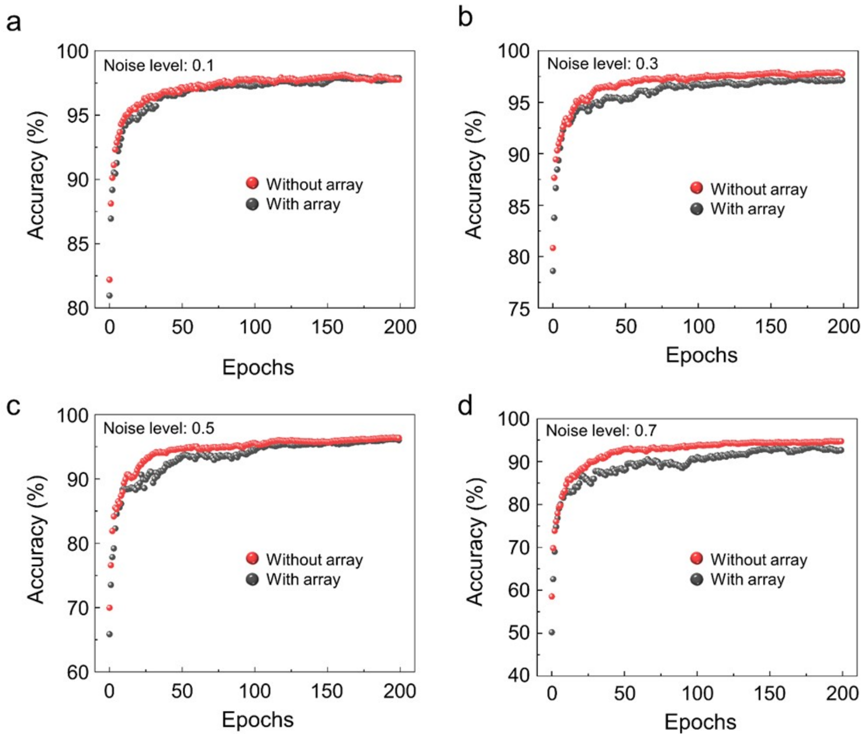

Fig. S11. The recognition rate with or without In_2O_3 TFTs array under the noise levels of 0,1, 0.3, 0.5, and 0.7.

Taking into account the increase in efficiency of the recognition task using In_2O_3 TFTs array, the number of epochs required to achieve different recognition accuracies, with and without the In_2O_3 TFTs array, is extracted from the simulation. Due to the similar structure of neural networks with In_2O_3 TFTs array and without In_2O_3 TFTs array, the power consumption and speed of a single epoch are roughly equal. Therefore, for the same accuracy, the entire processing speed is inversely proportional to the epoch, and the entire energy consumption is proportional to the epoch. The improvement rate is defined as:[5]

Rate of improvement (%) = (Epochs (without arrray) – Epochs (with array)) / Epochs (without array) × 100%.

Reference

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