

An Artificial Neuromorphic Somatosensory System with Spatio-Temporal Tactile Perception and Feedback Functions

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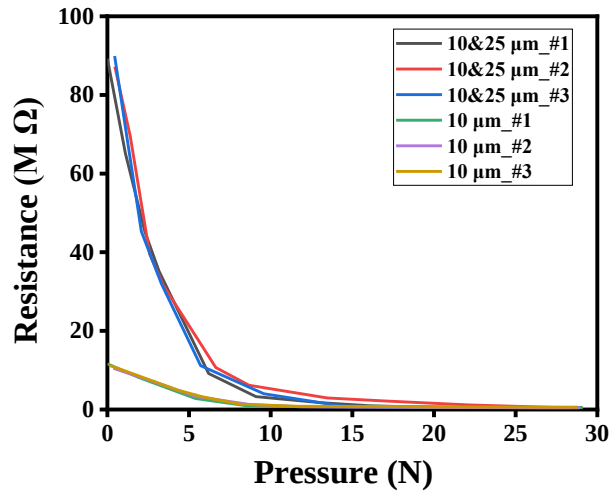
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Supplementary information

Supplementary Figure 1 shows the resistance change of the flexible tactile sensor under different pressures that fabricated from the same batch of silicon templates with different micro-nano structures. The initial resistance of the device with a hierarchically pyramidal microstructure is about ten times that of the device by using a single pyramidal microstructure. The flexible sensor is used as a pull-up resistor at the input end of the voltage-frequency conversion module (AD654). To achieve zero output of the module in the initial state (no pressure), the input of the module is required to be zero in the initial state. Therefore, the pull-up resistance needs to be much larger than the pull-down resistance, that is, the larger the resistance of the flexible tactile sensor, the better.

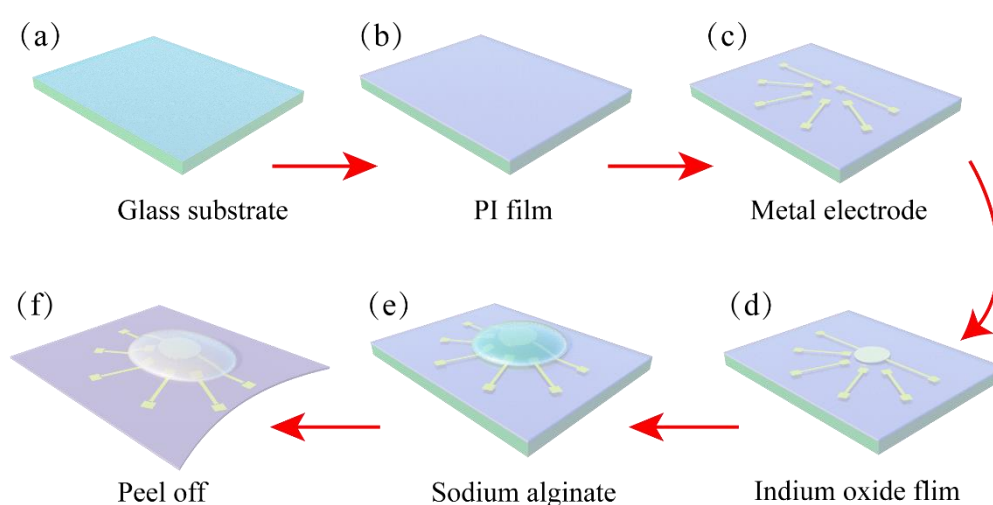


Supplementary Figure 1 Resistance change of the flexible tactile sensor under different pressures that fabricated from the same batch of silicon templates with different micro-nano structures.

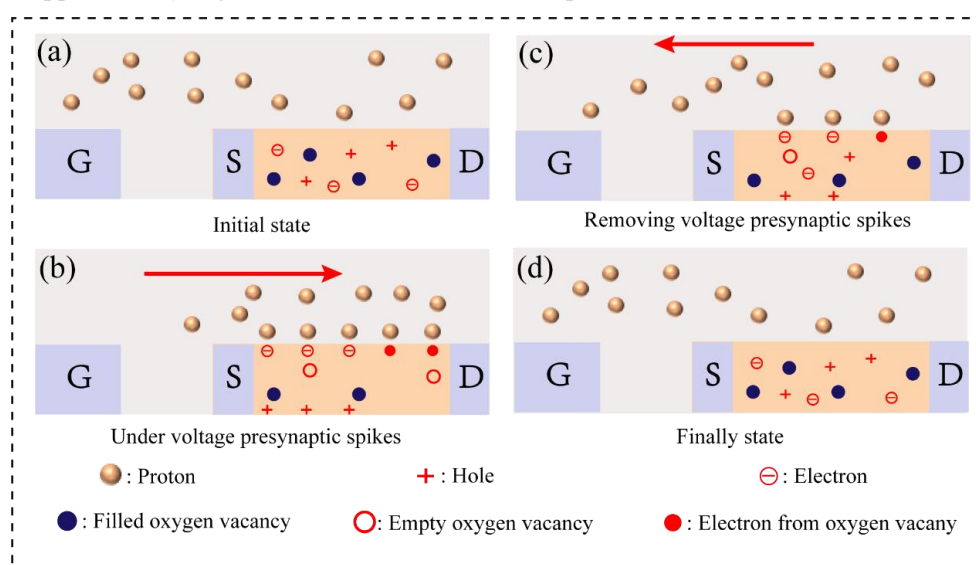
Supplementary Figure 2 shows the detailed fabrication process of the $\text{In}_2\text{O}_3/\text{SA}$ -based artificial synaptic transistor, which is described in the methods section of the manuscript.

Supplementary Figure 3 shows the schematic diagram of the $\text{In}_2\text{O}_3/\text{SA}$ -based flexible synaptic transistor working in the voltage presynaptic spikes. When voltage spikes are

applied to the gate electrode, protons will drift from the gate terminal to the In_2O_3 layer. Then, the EDL is formed at the interface between the SA membrane and the In_2O_3 and it attracts a large number of free electrons to the interface. Thus, a current in the channel is produced under a voltage between the source and drain electrode. With the end of the voltage spikes, the current gradually decays back to the initial state, which resembles the behaviour of biological excitatory synapses.

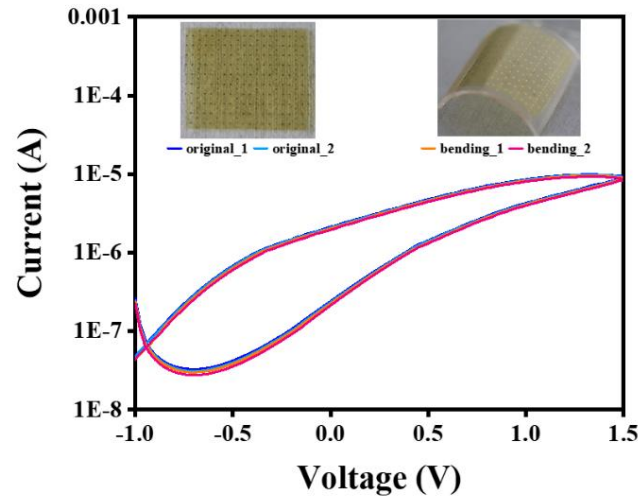


Supplementary Figure 2 The detailed fabrication process of the In_2O_3 /SA-based SFET.



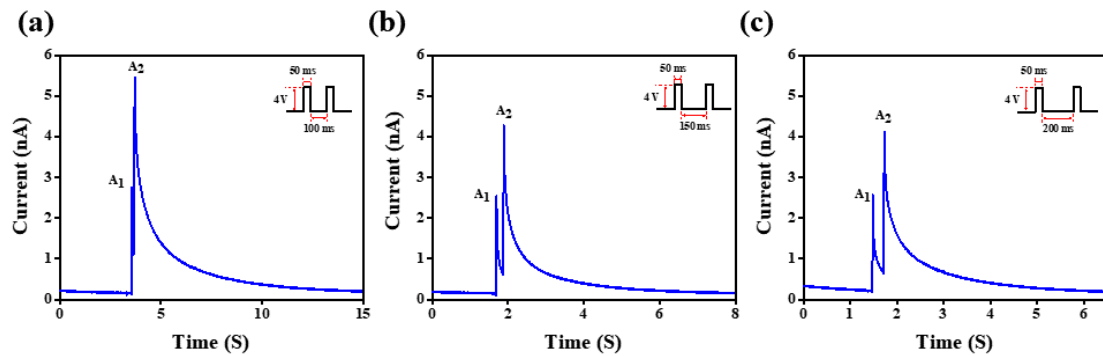
Supplementary Figure 3 The schematic diagram of the In_2O_3 /SA-based flexible synaptic transistor.

Supplementary Figure 4 shows the transfer characteristic curves of the device under planar and bending conditions. The curve remains reliable under bending conditions which demonstrates great flexibility and reliability of the devices.



Supplementary Figure 4 The transfer characteristic curves of the device under planar and bending conditions.

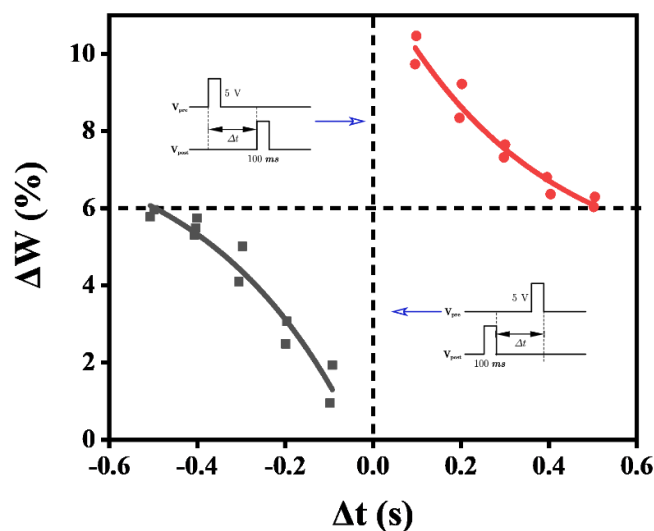
The EPSCs triggered by a pair of presynaptic optical spikes with different pulse intervals are shown in Supplementary Figure 5. The PPF (the ratio of the amplitudes, A_2/A_1) of the artificial synapse decreases gradually with the increasing pulse interval.



Supplementary Figure 5 The EPSCs triggered by a pair of presynaptic voltage spikes with different pulse intervals. A_1 and A_2 are the amplitudes of the first and second EPSCs, respectively.

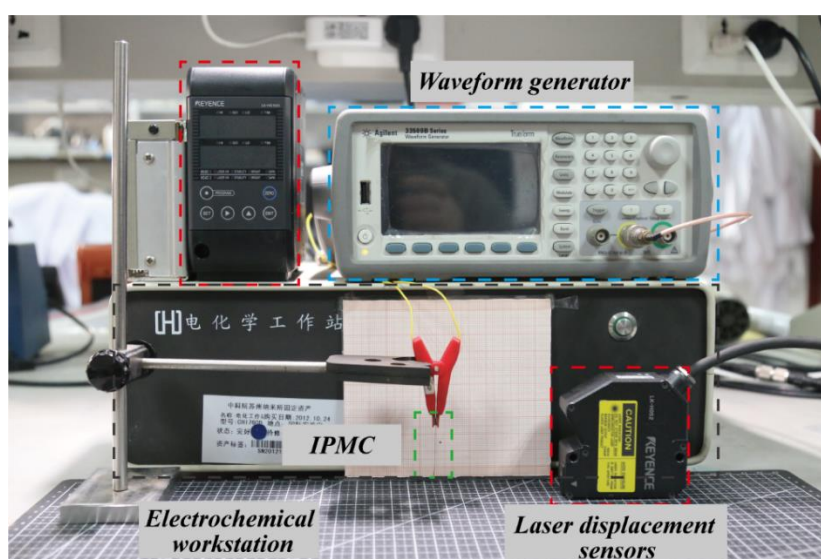
To implement the STDP functions, a pair of presynaptic spikes and postsynaptic spikes (5 V, 100 ms) with an interval time (Δt) is applied to the devices and the percentage of the channel conductance variation (ΔW) was tested (Supplementary

Figure 6, Supporting Information). The data of the ΔW relied on Δt can be well fitted with the exponential decay functions in Hebbian learning rules.



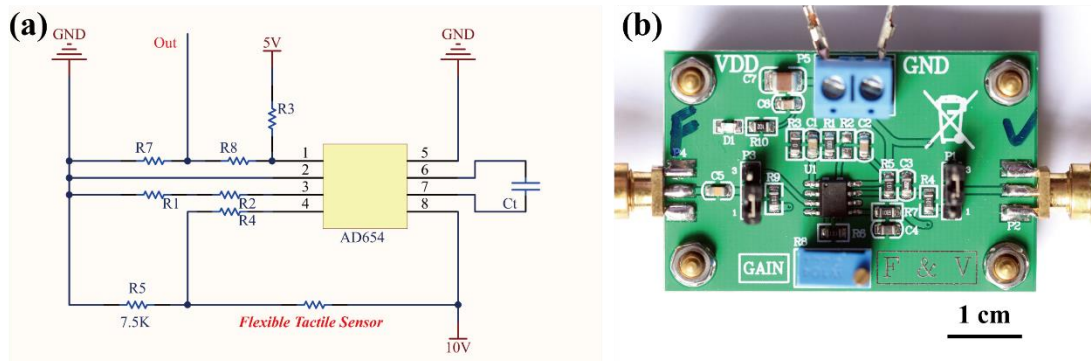
Supplementary Figure 6 The SDRP functions of the artificial synaptic transistor.

Supplementary Figure 7 shows the test equipment for the bending motion performance of the IPMC. The voltage spikes were generated by a waveform generator (Agilent 33510B). The current-voltage response and the displacement measurement of the IPMC were obtained using an electrochemical workstation (CHI990D) and a laser displacement sensor (Keyence, LK-H052), respectively.

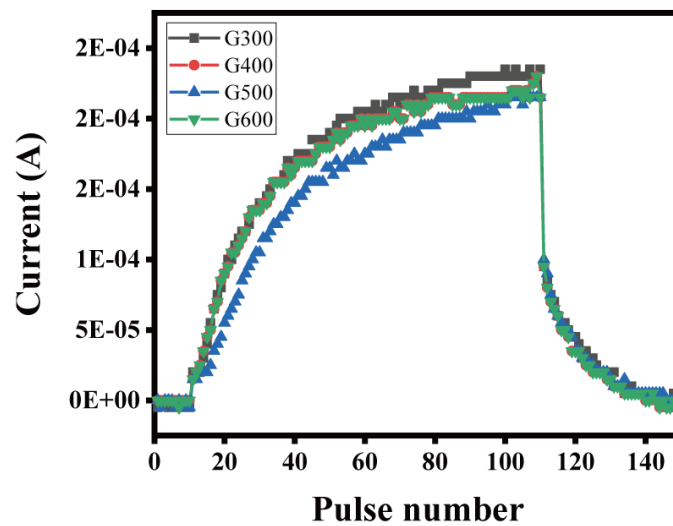


Supplementary Figure 7 The test equipment for the bending motion performance of the IPMC

Supplementary Figure 8 shows the circuit schematic diagram and physical diagram of the oscillator used in the artificial systems.

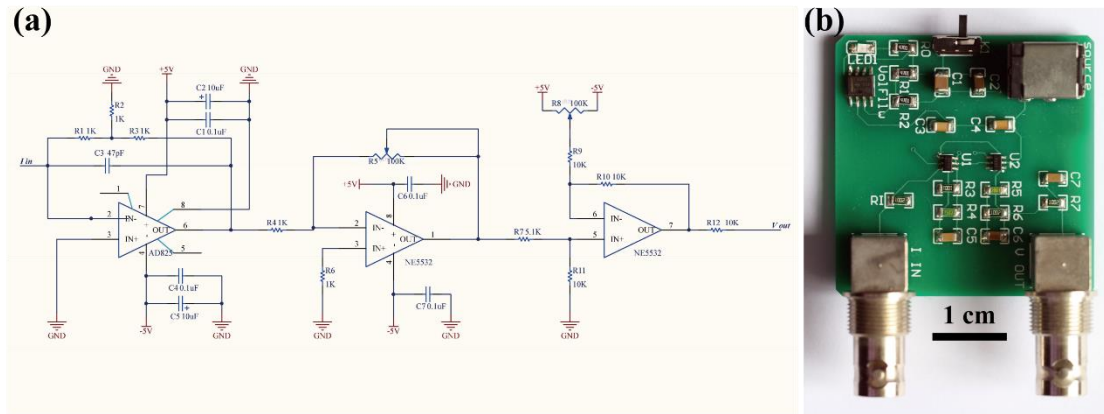


Supplementary Figure 8 Circuit schematic diagram (a) and physical diagram (b) of the oscillator.

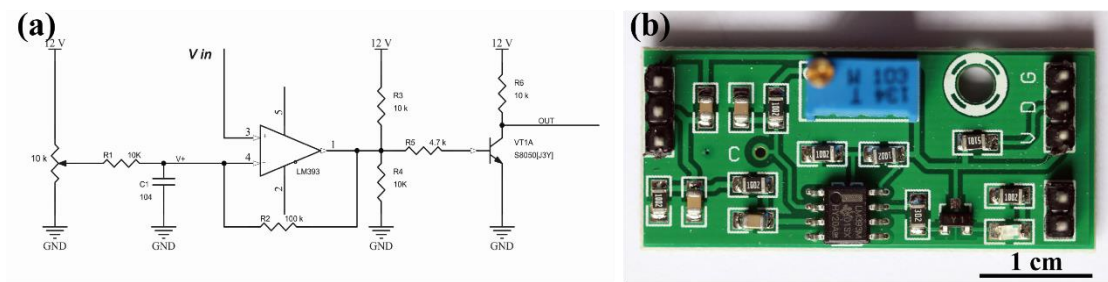


Supplementary Figure 9 The EPSC response of the multi-gate terminals synaptic transistors under the same gate voltage spike.

Supplementary Figure 10 and Figure 11 show the circuit schematic diagram and physical diagram of the I-V TIA and comparator used in the artificial systems, respectively.



Supplementary Figure 10 Circuit schematic diagram (a) and physical diagram (b) of the I-V TIA .



Supplementary Figure 11 Circuit schematic diagram (a) and physical diagram (b) of the comparator.

Supplementary Table 1 shows the ratio of the maximum value of EPSC to the initial value (L). The result indicated that the gradual increase of L with the distance, which proved that the system is sensitive to spatial stimuli.

Supplementary Table 1 The ratio of the maximum value of EPSC ($A_{\max}$) to the initial value (A_i)

G	Duration (s)	Magnitude (N)	L
300 μm	2	32.5	92
400 μm	2	32.5	119
500 μm	2	32.5	146
600 μm	2	32.5	186