**Supplementary Information**

**Ferroelectric photosensor network: an advanced hardware solution to real-time machine vision**

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**Figure S1.** (a) Low-magnification cross-sectional TEM image and (b) XRD *θ*-2*θ* diffraction pattern of the PZT/SRO/STO heterostructure.

Figure S1a shows that the PZT/SRO/STO heterostructure is well established and both PZT/SRO and SRO/STO interfaces are quite sharp. The thicknesses of the PZT and SRO layers are determined as ~120 and ~40 nm, respectively. Some dark lines are observed in the PZT layer, which may be attributed to the domain walls or misfit strain-induced dislocations.1,2

As shown in Figure S1b, only the (00*l*) peaks from PZT, SRO and STO are present, confirming the phase purity and the epitaxial growth of the PZT/SRO film. Based on the peak positions, the out-of-plane lattice constant of PZT is calculated as ~4.131 Å. On the other hand, the in-plane lattice constant is determined to be ~3.929 Å, based on the high-magnification cross-sectional TEM image (Figure 1c in the main text). These lattice parameters of PZT agree with those reported previously for the PZT films grown on the STO substrates.3



**Figure S2.** (a) Initial out-of-plane PFM phase image, and those measured (b,d,f,h,j,l,n) immediately after and (c,e,g,i,k,m,o) a few moments later after writing a 2 × 2 box sequentially with tip biases of (b,c) +3V, (d,e) +3.5V, (f,g) +4V, (h,i) -2.5V, (j,k) -3V, (l,m) -3.5V, (n,o) -4V. The waiting times before the PFM image scans are indicated in the corresponding panels.

It is seen that applying positive (negative) write voltage results in the black (yellow) contrast in the PFM phase image. Therefore, the black and yellow contrasts correspond to the downward and upward domains, respectively. As the positive write voltage increases (Figure S2b-g), a downward domain (in the right area) emerges, expands, and eventually fills up the whole written area. As the negative write voltage increases, a major upward domain (in the right area) and some minor upward domains (in the middle area) are formed and they gradually expand to dominate the whole written area (Figure S2h-o). The upward/downward mixed domain configurations are observed during the domain switching process, well accounting for the formation of multiple intermediate polarization states. Moreover, Figure S2c, e, g, i, k, m, and o show that all the domain states are stable. In particular, the retention of the +4 V written state was tested for 18 days. Almost no contrast changes are observed in the written area, confirming the stability of the switched domains.

To understand the origin of good domain stability, the observed domain switching mode may be further analyzed. As indicated by Figure S2, the domain switching is mainly contributed by the growth of a major switched domain. This suggests that the switched domain already penetrates through the film thickness and grows sideways. As a result, the switched domain can be well screened by charges in the two electrodes (or charges from the ambient if there is no top electrode), thus reducing the depolarization effect and enhancing the domain stability. In addition, the domain connecting the two electrodes can facilitate the transport of photo-excited charge carriers within the domain, which may contribute to the photocurrent stability.



**Figure S3.** (a) Long-term stability and (b) cyclability of photocurrents of the Pt/PZT/SRO FE-PS in different polarization states as set by applying -3 V, +2.4 V, +3 V, and -2.4 V pulses (pulse width: 0.15 ms) sequentially. In b, the light is switched ON and OFF alternately with 10 and 30 seconds for the ON and OFF periods, respectively.

Four different polarization states: complete *P*up, incomplete *P*down, complete *P*down, and incomplete *P*up states, were obtained by sequentially applying -3 V, +2.4 V, +3 V, and -2.4 V pulses, respectively. Figure S3a shows that the photocurrents measured in all the polarization states are quite stable. Such different photoresponsive states can be retained for at least 24 hours. Figure S3b demonstrates that the photoresponsive states are reproducible during the frequent ON/OFF illumination cycling.



**Figure S4.** (a) *P-V* hysteresis loops and (b) photocurrents in the complete *P*up and *P*down states measured for the Pt/PZT/SRO FE-PS after different fatigue cycles.

The FE-PS was switched by 3 V/10 μs pulses for 106 cycles. As shown in Figure S4, both the *P-V* hysteresis loops and the photocurrents show almost no changes during the fatigue test, demonstrating the good endurance of the FE-PS.



**Figure S5.** (a) *P-V* hysteresis loops and (b) photocurrents in the complete *P*up and *P*down states measured for 11 Pt/PZT/SRO FE-PSs.

The different FE-PSs exhibit similar polarization switching behavior and photocurrent responses. The device-to-device variation of photocurrents is estimated to be ~3.2% for the FE-PSs.



**Figure S6.** Dependences of photocurrent on light intensity of the Pt/PZT/SRO FE-PS in different polarization states as set by applying -3 V, +2.4 V, +3 V, and -2.4 V pulses sequentially.

The photocurrents in all the different polarization states exhibit linear relationships with the light intensity. The linearities of these curves are greater than ~0.94. The linear dependence of photocurrent on light intensity allows the photoresponsivity to be well defined. It is also a prerequisite for the multiplication operation in the FE-PS.



**Figure S7.** Transient current responses upon (a) illumination ON and (b) illumination OFF.

The photocurrent generation and decay times are measured to be ~100 ms, which reach the time resolution limit of our measurement system. Previous studies4,5 using pulsed laser and high-speed oscilloscope demonstrated that the photocurrent generation and decay times could be below 1 ns.



**Figure S8**. Typical monopolar *P-V* hysteresis loops measured with (a) 2 V/10 μs and (b) -2 V/10 μs pulses.

Using the shaded areas shown in Figure S8a and b, the energies consumed by the positive and negative writing processes are calculated to be ~3.6 nJ and ~2.5 nJ, respectively, giving rise to an average energy consumption of ~3.1 nJ.

**Supplementary Note 1.**

To highlight the low latency of the FE-PS-NET for image processing, a performance comparison was made between the FE-PS-NET and a conventional Von Neumann system comprising a camera, a memory, and a processor. A 10-million-pixel image showing one of the ten digits (‘0’ to ‘9’) was assumed as the image to be detected and processed. The image processing task was assumed to be the classification of this image into one of the classes ranging from ‘0’ to ‘9’.

A 10 × 107 (*M* = 10 and *N* = 107) FE-PS-NET was used for the simultaneous detection and processing of the image. As mentioned in the main text, the photocurrent generation time could be neglected compared with the RC time constant of the circuit, and the latter was considered to be mainly responsible for the latency. To estimate it, each FE-PS was assumed to have a small area of ~1 μm2 and a resistance of ~5.7 × 1010 Ω.6 In addition, the thickness and dielectric constant of the PZT film in the FE-PS were assumed to be ~120 nm and ~180,7 respectively, giving rise to a capacitance of ~1.3 × 10-14 C for the FE-PS. Using these parameters of FE-PS, we simulated a 10 × 107 FE-PS-NET (divided into multiple tiles) with current-sense-amplifiers (for current detection) in the NeuroSim simulator.8 The latency was calculated to be ~2.6 μs.

In terms of the Von Neumann system, the image capture time consumed by a 10-megapixel camera (assuming a HP RJ23W3BA0KT CCD camera) was estimated to be ~20 ms. The image storage time was not estimated due to the lack of data. For the image processing, a NVIDIA GTX1650 GPU (memory size: 4 GB; memory clock: 8 GHz) was used. By running the matrix-vector multiplication involved in the classification task on the GPU, the image processing time was estimated to be ~0.77 ms. The total latency of the Von Neumann system was thus at least ~20.77 ms, which was four orders of magnitude longer than that of the FE-PS-NET.

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