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A sensing-memory-computing integrated optoelectronic synaptic device based on Ag/$PtTe_2$/FTO for artificial vision information processing

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The conventional von Neumann architecture faces escalating energy demands in the AI era, particularly for vision tasks where sensing, memory, and processing are physically separated. While bio-inspired neuromorphic computing offers a paradigm shift, a critical dilemma persists in hardware implementation: purely electrical synapses lack inherent photonic sensitivity, necessitating redundant sensors and data transfer [1], whereas purely optical synapses typically suffer from signal volatility, rendering them unsuitable for reliable non-volatile weight storage [2]. To bridge this gap, we introduce a synergistic "optical sensing-electrical storage" strategy based on a two-terminal Ag/$PtTe_2$/FTO device. By integrating the broadband optical absorption of 2D $PtTe_2$ with non-volatile resistive switching [3], our architecture uniquely assigns real-time event capture to the optical domain, and stable weight consolidation to the electrical domain. This functional stratification effectively resolves the trade-off between sensing and non-volatility, integrating sensing, memory, and computing within a single platform (Figure 1(a)).

The device, fabricated via a scalable solution-processing method, features a vertical Ag/$PtTe_2$/FTO structure. Material characterizations confirm the high-quality 1T phase of the $PtTe_2$ nanosheets [4] and their broadband optical absorption spectrum (Appendix A). Comprehensive electrical characterizations confirm stable bipolar resistive switching (Figure 1(b)) with excellent retention and high uniformity across devices, ensuring reliable non-volatile weight storage (Appendix B). Optically, the device emulates multi-wavelength self-powered synaptic behaviors (405–780 nm). It successfully reproduces essential biological plasticity rules, including spike-number-dependent plasticity (SNDP) (Figure 1(c)), various spike-dependent plasticities (SWDP, SRDP, SPDP), paired-pulse facilitation (PPF), and higher-order learning-forgetting-relearning behaviors. Statistical analysis across five independent devices confirms excellent reproducibility, evidenced by narrow distributions in electrical switching parameters and optical metrics (Appendix B). The underlying mechanism is attributed to the Schottky barrier at the $PtTe_2$/FTO interface (Figure 1(d)). Light illumination generates electron-hole pairs separated by the built-in electric field; the competition between carrier generation and recombination results in a natural, volatile decay of the photocurrent [5] (Appendix C). The device's intrinsic optical self-powered operation is substantiated by wavelength-dependent open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}) measurements, alongside rapid optical switching dynamics (Appendix B).

We leverage this unique combination to demonstrate two hierarchical applications via system-level simulations. First, inspired by the human retina, we emulated in-sensor image denoising. Exploiting experimentally the devices' measured nonlinear photoresponse, where high-intensity light triggers a strong current while low-intensity light is suppressed, we effectively filtered input signals (Figure 1(e)). The synaptic weights of the subsequent convolutional neural network (CNN) were mapped to the devices' real non-volatile electrical conductance states (derived from LTP/LTD measurements). This synergistic approach—utilizing optical nonlinearity for "in-sensor" denoising and electrical non-volatility for weight storage—improved the recognition accuracy of noisy images from ∼40% to 90% (Figure 1(f)), closely approaching the noise-free baseline (Appendix D).

Furthermore, extending this architecture to the time domain, we exploited the device's intrinsic optical volatility to resolve spatiotemporal information. In our simulated array, moving objects generate sequential optical stimuli. Due to the natural decay of the photocurrent, the "memory" of a past frame persists but is weaker than the current frame, creating a spatiotemporal gradient that encodes motion direction (Figure 1(g)). By combining this

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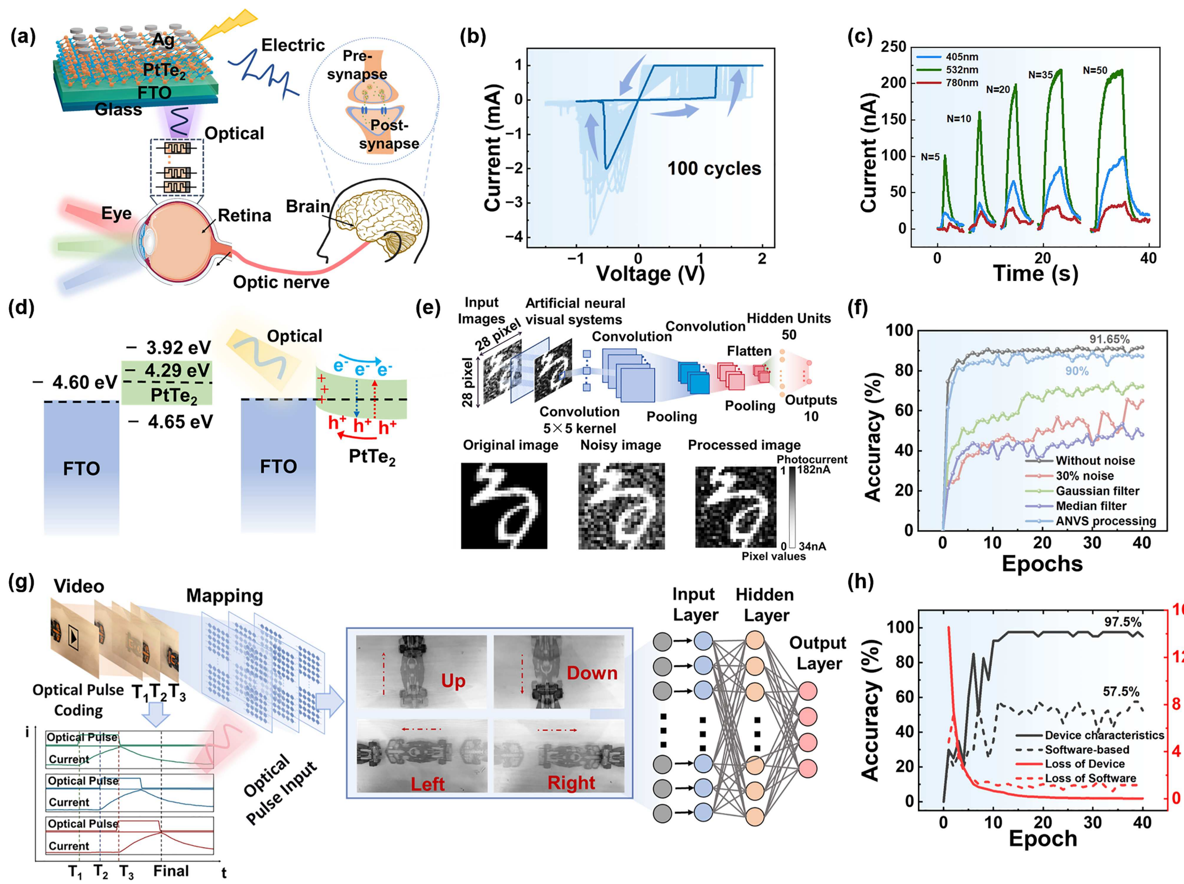

Figure 1 (Color online) (a) Schematic of the bio-inspired vision system integrating sensing, memory, and computing via optoelectronic synergy; (b) current-voltage (I-V) characteristics of the synaptic device; (c) evolution of the photocurrent response under varied numbers of optical pulses at 532, 405, and 780 nm; (d) band alignment and carrier dynamics under optical pulses; (e) architecture and denoising performance of the bio-inspired vision system; (f) recognition accuracy comparison between ideal, noisy, and variously denoised images; (g) neuromorphic motion detection and trajectory classification system; (h) motion direction recognition accuracy over the entire experimental period.

optical temporal processing with the electrically trained classifier, the system achieved a 97.5% accuracy in recognizing motion trajectories (Figure 1(h)), significantly outperforming software-based approaches (57.5%) and validating the robustness of the hybrid optoelectronic architecture (Appendix E).

In this study, our Ag/$PtTe_2$/FTO device synergizes volatile optical sensing with non-volatile electrical memory to emulate the retinal-cortical pathway. Validated by image denoising and trajectory recognition tasks, this strategy offers an energy-efficient platform to overcome sensing-computing bottlenecks in next-generation neuromorphic vision systems.

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Supporting information Appendixes A–E. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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