Defect-Engineered 2D Bi_2Te_3 Based Broadband Optoelectronic Synapse for Neuromorphic and Optical Information Processing

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The development of optoelectronic synapses (OES) has conventionally depended on complex device architectures, including multi-transistor designs, sophisticated fabrication processes, and multilayer heterojunction stacks. These requirements significantly hinder large-scale integration and practical implementation. In this work, we present a simple two-terminal OES device based on two-dimensional semiconducting Bi_2Te_3, a material whose potential for optoelectronic synaptic applications has remained largely unexplored. The proposed single-device platform is multifunctional, enabling applications in neuromorphic computing, biometric recognition, and artificial visual perception. The operating mechanism of the device is governed by persistent photoconductivity arising from tellurium (Te) vacancies introduced during thin-film deposition. These vacancies serve as effective charge trapping and de-trapping centers. By precisely controlling the annealing temperature of thermally evaporated Bi_2Te_3 films, we achieve tunable defect engineering and establish a direct correlation between vacancy states and device performance. The pivotal role of Te vacancies is further confirmed through first-principles calculations and comprehensive material characterization. The resulting device exhibits excellent optoelectronic synaptic behaviors, including a high paired-pulse facilitation (PPF) of 191.7% and an ultra-low energy consumption of 37.2 fJ per spike. In addition, the OES demonstrates classical associative learning (Pavlovian behavior) through its wavelength-dependent response. A 6 × 6 device array, functioning as an artificial retina, shows strong image retention with a memory performance of 57.4%. In computational demonstrations, the device achieves high accuracies of 93.3% in facial recognition and 86.7% in urban traffic scene segmentation using only 100 training epochs. Moreover, the fabricated devices support optical logic gate operations and Morse code decoding, underscoring their potential for optical signal recognition and wireless communication applications.

References

[1] S. Nandi, S. Ghosal, G. Choudhary, S. S. Roy, M. Meyyappan and P. K. Giri, *Small, 2026.* https://doi.org/10.1002/smll.202511836