Single-Crystalline $PbTiO_3$-Based Ferroelectric Memristors for Synaptic Plasticity Emulation

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In recent years, considerable focus has been directed towards leveraging ferroelectric perovskite thin films to actualize memristors[1-2] as the fundamental units of neuron networks, which can process data at the location where it is stored. Herein, memristors using ferroelectric $PbTiO_3$-based thin films are experimentally developed, with a reservoir of oxygen vacancies induced during the fabrication process, i.e. pulsed laser deposition or spin-coating. The single-crystalline growth and epitaxial growth have been confirmed by X-ray diffraction φ-scan and reciprocal space mapping, respectively. In Fig. 1(a), the current-voltage (*I*-*V*) characteristics reveal stable resistive switching behaviors even after 100 sweeping cycles, indicating highly repetitive resistive switching. Their resistive switching behaviors are also confirmed under different maximum voltages and various voltage step widths. The conduction mechanisms are studied by fitting different conducting models. With tunable resistances, several phenomena of analog switching, single-pulse facilitation, paired-pulse facilitation, short-term memory (STM), long-term memory (LTM), and spike-timing-dependent plasticity (STDP)[3] in response to pulse training can be experimentally mimicked in $PbTiO_3$-based memristors. As shown in Fig. 1(b), the dynamic transitions from STM to LTM can be observed under different training pulses, where each cycle of training contains 30 and 100 pulses, respectively. During a cycle of pulse training, the resistance undergoes a potentiation process under pulse stimuli and then decreases after the stimuli are removed. These pulse trainings clearly reveal the learning and forgetting processes. The memory level increases with the number of pulse stimuli, and these characteristics are analogous to human memory in the brain. A pronounced transition from STM to LTM is observable after repeated rehearsal of training. As shown in Fig. 1(c), the functionality of STDP is achieved, indicating the capability of $PbTiO_3$-based memristors as practical artificial synapses. The STDP characteristics under varying spike amplitudes and durations have been explored. The exponential decay results show the typical Hebbian learning rule of a neuromorphic learning system, exhibiting long-term potentiation (positive $\Delta G/G_0$) when $\Delta t > 0$ and long-term depression (negative $\Delta G/G_0$) when $\Delta t < 0$.

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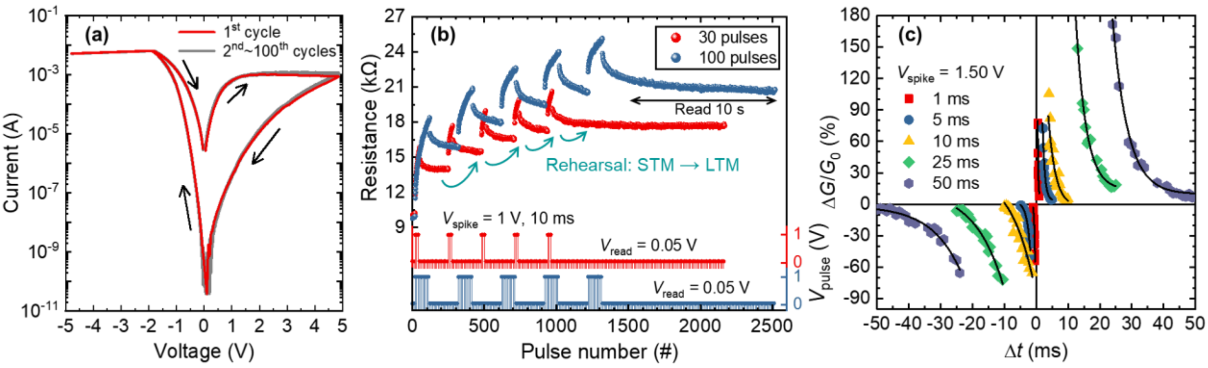

Fig. 1(a) *I*-*V* characteristics for the $PbTiO_3$ thin film, with the direction of voltage scanning indicated by black arrows. The resistive switching for 100 continuous sweeping cycles is also shown. (b) Experimental demonstration of the memory model in the memristive $PbTiO_3$ synapse, indicating the conversion from STM to LTM. The pulse sequences consist of 30 and 100 pulses for each cycle, respectively. (c) Asymmetric STDP characteristics demonstrating Hebbian learning.