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Resistive Switching Device for Neuromorphic Device Application

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1. Introduction

We investigated the various Spike Timing Dependence Plasticity (STDP) synaptic rules using resistive switching device. Potentiating and depressing with the time difference between pre- and post- neuron synapse is the key idea of STDP synaptic rule. We showed the potentiating and depressing of the device with applied pulse and its uniformity and other STDP rules: frequency dependency, weight dependency on the device for future neuromorphic device.

2. Experimentals

Pt/Al/TiO_{2-x}/TiO_2/W device was fabricated on the 250nm via hole substrate. 6 nm-thick TiO_2 layer was deposited by ALD at 250 °C and above the layer, 50 nm-thick sol-gel TiO_{2-x}, made of Titanium (Ⅳ) isopropoxide [1], layer was deposited. After deposition, the device was thermally annealed at 400 °C for 2 hrs under nitrogen ambient. After conventional lithography process, 15 nm thick Al and 100 nm thick Pt as top electrode were deposited at room temperature by RF magnetron sputtering then top electrodes were patterned. A schematic diagram of the device structure is shown in Fig. 1 (b).

3. Results & Discussion

The Fig. 1 (a) shows schematic concept of resistance switching device performs as synapse. Resistance switching device has multi-level of conductance shown in Fig. 2 caused by oxygen movement between oxygen rich TiO_2 layer and oxygen poor TiO_{2-x} layer [2]. With the positive 15V DC voltage sweep the conductance of the device was increased and vice versa in inset graph of Fig. 2. This tunable conductance can mimic the synaptic plasticity rules [3], with the input signal of the neuron, the efficiency (weight) of the synapse between two neurons is changed, in nanoscale resistance switching device. Particularly, we confirmed that STDP, important synaptic adaptation function for learning and memory [4], can be mimicked by the resistive switching device.

Fig. 3 shows the continuous change of increase (blue) and decrease (red) of conductance (read at -5V) by identical series of 100 times applied positive potentiating(P) pulse (20V, 10ms) and negative depressing (D) pulse (-15V, 10ms) respectively. The Cumulative probability distribution of after few times of P and D pulses are shown in the Fig. 4 and Fig. 5 respectively. This uniformity is measured 50 times at one cell with P pulse (15V, 25ms, Fig. 4) and D pulse (-11V, 25ms, Fig. 5). The average value and standard deviation value of after 35 times P pulse and after 5 times of D pulse are shown in the each Fig.4 and 5 inset table. With Fig. 4 and 5, we can confirm certain change of the device conductance state after over 10 times of P/D pulses. Fig. 4, 5 inset graphs are one of P and D pulse changed conductance graph respectively. Fig. 6 shows measured conductance change (read at -5V) by mixed P (15V) and D (-10V) voltage pulse with different pulse widths. A specific correlation between conductance change and pulse width of the applied P/D signals was observed. With increasing pulse width, the conductance change also increases.

Change of the device weight (conductance) after applied pulse vs calculated time difference between two neurons is fitted in Fig. 7 and inset graph. These graphs show the characteristic of exponential increase and decrease of biological synaptic STDP characteristic [4].

Biological synapses have timing plasticity rule, the increased weight change with the increased frequency of signals in the inset of Fig. 8 [5]. We measured conductance of the device with same P (15V, 10ms) pulse and various D (-10V, 50ms to 10ms) pulse to see the repetition of signal frequency effect on the device. Fig. 8 shows increased conductance changes with the increased frequency same as biological synapse.

The weight change can be depended on the current weight state in the biological synapse [6]. Fig. 9 shows the conductance change dependency by current conductance in the device like biological synapse model. Furthermore, with the increased and decreased voltage, the graph is more linear in Fig. 9 (a) and (b) respectively. Therefore, we can select desirable linearity by changing voltage.

4. Summary

For future neuromorphic device application, we demonstrate the possibility of resistance switching device for various STDP characteristic of the synapse between neurons. The potentiating and depressing of the synapse with the timing, its uniformity, repetition frequency effect, and conductance dependency of the device were investigated.

Acknowledgments

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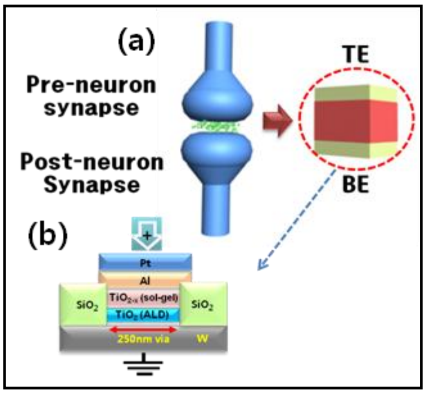

Fig. 1 (a) Schematic illustration of the concept of using resistance switching device as synapses between neurons. (b) Schematic diagram of Pt/Al/TiO_{2-x}/TiO_2/W 250nm hole substrate device structure.

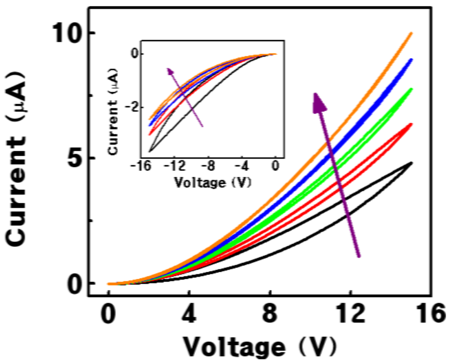

Fig. 2 I-V characteristics during 5 times of 15V and -15V (inset) DC voltage sweep.

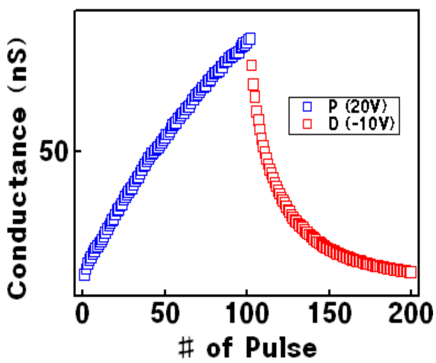

Fig. 3 Responding to programming pulses. Device conductance is increased with positive (P, 20V, 10ms) pulse and decreased with negative (D, -10V, 10ms) pulse. Conductance is measured at -5V.

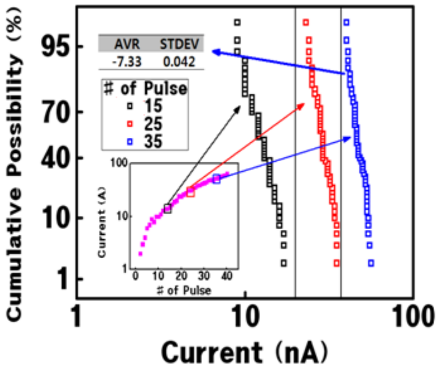

Fig. 4 The cumulative probability of current distribution after applied 15, 25, 35 times potentiating (15V, 25ms) pulse at one cell of the device.

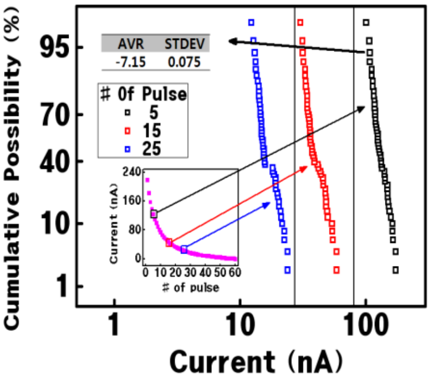

Fig. 5 The cumulative probability of current distribution after applied 5, 15, 25 times depressing (-11V, 25ms) pulse at one cell of the device.

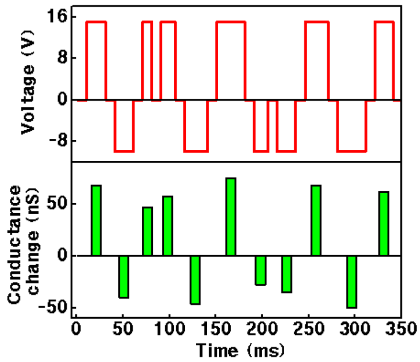

Fig. 6 (Top) Mixed potentiating and depressing pulses with different pulse widths. (Bottom) Measured change of the device conductance after applied each pulse.

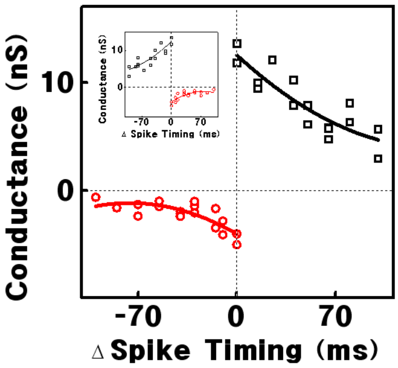

Fig. 7 STDP synaptic graph of the device. The measured change of the device conductance (synapse weight) vs calculated relative timing Δt.

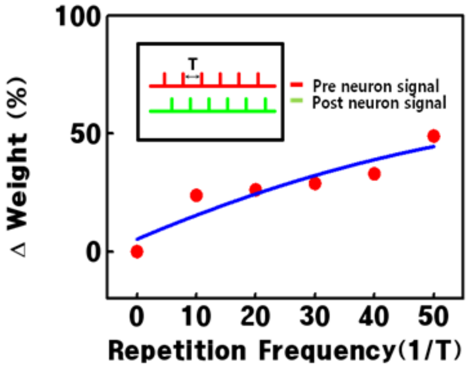

Fig. 8 Frequency dependency of potentiating of the device. With same number of pre-post parings repeated with decreased time interval T the weight (conductance) of the device increased.

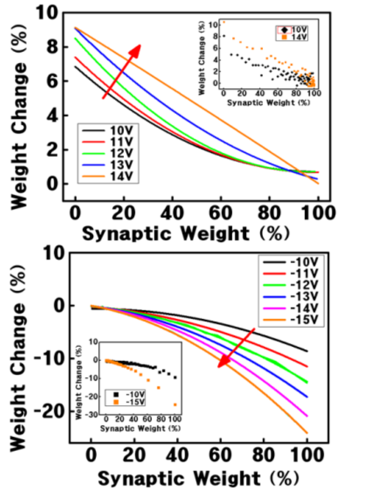

Fig. 9 Weight (conductance) dependence of conductance change with (a) increased positive pulse (25ms) and (b) decreased negative pulse (25ms).