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Supporting Information

Volatile threshold switching and synaptic property controlled by Ag diffusion using Schottky defect

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Figure S1. I-V curve of bilayer with HfO_2/Ta_2O_5 different thickness of 4nm/8nm and 6nm/6nm. (a) The diffusion I-V behaviors with HfO_2/Ta_2O_5 of 4nm/8nm and (b) 6nm/6nm. A variation in the I-V curve appeared when the Ta_2O_5 thickness was greater than 4nm in the total thickness of 12nm, indicating that the control of the Ag filament is not stable in these devices.



Figure S2. Relaxation time of bilayer with HfO_2/Ta_2O_5 different thickness of 4nm/8nm, 6nm/6nm and 8nm/4nm after applying a 5V/0.05ms pulse. (a) Change in current over time during and after a 5V/0.05ms pulse with bilayer devices. (b) Relaxation time of bilayer devices after the pulse. In plot (a), the time after the pulse was replotted, and the time was calculated by FFT fitting.



Figure S3. DC and pulse endurance of bilayer device with HfO2/Ta2O5 thickness of 8nm/4nm. (a) Endurance of DC cycles, (b) statical variation of VSET, (c) LRS and HRS current. (d) The pulse endurance of bilayer device.



Figure S4. Atomic percentage of (a) HfO_2 , (b) Ta_2O_5 , and (c) bilayer with HfO_2/Ta_2O_5 using XPS. The atomic percent of oxygen was the highest around near the interface Ta_2O_5 and HfO_2 layer.



Figure S5. Ag atomic percentage with vertical profiles obtained through line EDX analysis. (a) Single layer HfO_2 , (b) single layer Ta_2O_5 , and (c) bilayer Ta_2O_5/HfO_2 samples were prepared in the SET state. The Ag atomic percentage is observed to decrease within the oxide layer located between the two red lines.



Figure S6. Ag atomic percentage with vertical profiles obtained through dot EDX analysis form region 1 to 3. (a) Single layer HfO_2 , (b) single layer Ta_2O_5 , and (c) bilayer Ta_2O_5/HfO_2 samples were plotted as graph in (d), (e) and (f), respectively. The Ag atomic percentage is the highest percentage in the single layer device of HfO_2 and the lowest in the bilayer device.



Figure S7. The LIF characteristic with 0.2 V/0.01 s pulse and 0.1 V read voltage using the Ag diffusion memristor. (a) LIF characteristic that was an analog to a basic spiking neuron behavior. (b) Cartoon of biological neuron; A neuron received the input spikes from other neurons through the synapses and triggered the output action potential in case over the threshold value.



Figure S8. The property of the synaptic plasticity. (a) The short-term plasticity showing a temporary increasing current level. (b) The decreasing part of the short-term plasticity that was influenced by a previous pulse history.