Supporting information

Interface Engineered reliable HfO$_2$-based RRAM for Synaptic Simulation

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Table. S1. O$_3$-induced changes of area, max intensity and FWHM from TiN, TiON and TiO$_2$ spectra.
Fig S1. N 1s spectra detected on the TiN surface with various O$_3$ treatment: (a) 0 O$_3$ Pulse, (b) 10 O$_3$ Pulses, (c) 20 O$_3$ Pulses and (d) 40 O$_3$ Pulses.
Fig.S2. O 1s spectra detected on the TiN surface with various O$_3$ treatment: (a) 0 O$_3$ Pulse, (b) 10 O$_3$ Pulses, (c) 20 O$_3$ Pulses and (d) 40 O$_3$ Pulses.

Fig.S3. 300 loops of I-V curves of proposed RRAM with different O$_3$ treatments: (a) 0 O$_3$ Pulse, (b) 10 O$_3$ Pulses, (c) 20 O$_3$ Pulses and (d) 40 O$_3$ Pulses.
Fig. S4. DC endurance characteristics of proposed RRAM devices with the read voltage of -0.2 V: (a) 0 O₃ Pulse, (b) 10 O₃ Pulses, (c) 20 O₃ Pulses and (d) 40 O₃ Pulses.

Fig. S3 shows 300 loops of I-V curves collected in experiment. All samples are subject to the same test parameters: CC = 1mA, sweep voltage of -2 ~ 0 V/0 V ~ 2 V in Set/Reset process. Fig. S4 presents DC endurance characteristics of 0, 10, 20 and 40 O₃ Pulses, that 300 data are extracted from relevant 300 continuous I-V curves shown in Fig. S3. Obviously, it exhibits best stability and moderate ratio in case of 20 Pulses.

Fig. S5. ON/OFF ratio versus different pulses of O₃ treatment.
Fig. S6. Comparison of endurance characteristics between cases of annealed and non-annealed: (a) cumulative probability, (b) $V_{\text{Forming}}$, (c) $V_{\text{Set}}$ and (d) $V_{\text{Reset}}$.

Fig. S7. DC retention of proposed RRAM, with the read voltage of 0.2 V and the interval of 10s.
Fig.S8. Analog resistance of proposed RRAM devices in DC mode: (a) 0 O$_3$ Pulse, (b) 10 O$_3$ Pulses, (c) 20 O$_3$ Pulses and (d) 40 O$_3$ Pulses.