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Co-Integration of an Analog, CMOS-Compatible Electro-Optical Conductive Metal-Oxide/HfO_2 Memristor with Si Photonics

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Emulating biological learning rules through neuromorphic hardware is key to create energy-efficient computing systems for artificial intelligence. In this regard, neo-Hebbian three-factor learning rules are of particular interest as they describe the influence of global neuromodulators on synaptic plasticity and thus allow for biologically plausible realizations of reinforcement learning algorithms[1]. Three-terminal memristors are ideal candidates to directly implement three-factor learning rules on-device, provided that the third terminal can modulate their conductance independently from the two conventional electrodes[2]. Moreover, the emulation of synaptic plasticity also requires a continuous linear and symmetric conductance modulation.

Here, we demonstrate a novel vertical electro-optical memristor based on the valence change memory (VCM) technology that is co-integrated with a Si photonic waveguide acting as the third independent terminal (Fig. 1a-b). The optical signal induces a temperature increase of the active oxide layers (Fig. 1b). When a series of optical pulses is supplied through the underlying waveguide and combined with an electrical signal, both volatile and non-volatile conductance changes are observed (Fig. 1c). We further show that the purely electrical "conductance vs. number of voltage pulses" modulation exhibits a linear and symmetric potentiation and depression behavior (Fig. 1d). Our compact design approach allows for scaling-up to arrays of electro-optical memristors that are located on a single waveguide. Similar to neuromodulators in biology, the light signal could globally and simultaneously affect multiple devices.

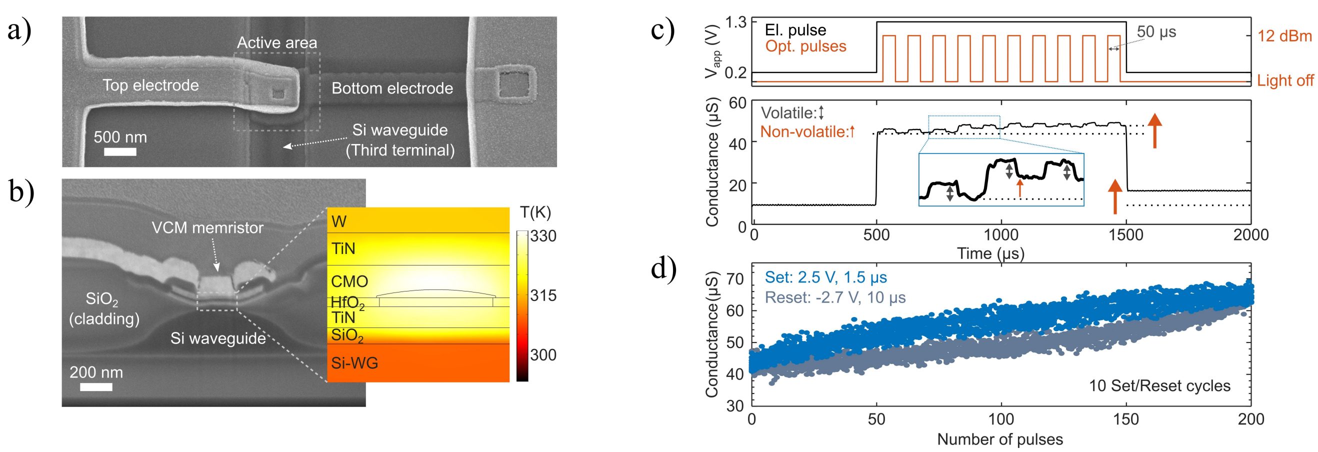

Figure 1: a) SEM picture of a fabricated vertical electro-optical memristor. An electrical TiN/HfO_2/Conductive Metal-Oxide (CMO)/TiN/W VCM memristor is co-integrated with a Si waveguide. b) FIB cross-section and simulated temperature distribution of the optically induced heating for 12 dBm input power. The 13 nm thin TiN bottom electrode ensures optimal coupling of the light to the active layers (i.e., HfO_2/CMO). c) Electro-optical interaction in a dynamic experiment. The optical pulses modulate the conductance thereby inducing volatile (grey) and non-volatile (red) changes. d) Electrical conductance as a function of number of pulses showing the analog and uniform behavior.

References

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