Ferroelectric materials for neuromorphic computing technologies

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An introduction on memristors with a brief historical survey will first be presented, emphasizing their relation to biological systems. A review on emerging non-volatile memory devices functioning as memristors will follow with a special focus on the ferroelectric memristors which offer a number of technology implementations (FRAM, FeFET, FTJ) to cover a wide spectrum of applications.

Hafnia based ferroelectrics (e.g. $Hf_{0.5}Zr_{0.5}O_2$ (HZO)) are of particular interest due to compatibility with Si processing. The HZO FTJ two terminal devices stand-out for their simplicity, non-destructive read and low voltage/low power operation. Their performance and reliability are enhanced by using functional bottom electrodes made of oxide semiconductors such as STO. These oxides allow for epitaxial or textured growth of HZO with improved ferroelectric switching characteristics. Also, they contribute additively to the electroresistance with ionic effects enhancing the performance of the FTJs.

The HZO FTJ devices show various types of synaptic plasticity making them suitable as electronic synapses in artificial neural networks in hardware. They can be programmed by voltage pulses to a number of stable intermediate states which could be accessed by identical pulses or variable width pulses creating prospects for use in AI accelerators for analog in-memory computing. Moreover, the HZO FTJ memristors exhibit spike timing dependent plasticity (STDP) featuring potentiation or depression of a synapse depending on the synchronization of pre-and post-neuron pulses. This property emulates synaptic dynamics of biological synapses and it can be used for unsupervised learning in spiking neural networks (SNN) for next generation neuromorphic computing. We will show that, using HZO FTJs, biological timescales of a few tens of milliseconds are accessible. Much faster STDP time responses are also obtained down to the (sub)microsecond range, albeit with an increased voltage (and power) consumption. Despite the time-to voltage trade-off it is shown that the energy consumption due to Joule heating is negligibly small because FTJs are voltage driven devices consuming only the energy necessary to charge the ferroelectric capacitors. As a result, the energy consumed per synaptic event is low, comparable to biological numbers of ~ 10 fJ. Therefore, HZO FTJ technology provides an excellent platform for energy efficient chips powered by AI.

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