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Exploring Memristive Squaraine Nanowire Networks: Programmable Multi-Level Memory Behaviour for Neuromorphic Applications

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Abstract:

Typically, the demand for faster, cheaper, more efficient computing has been answered by device miniaturisation. However, device down-scaling (particularly that of transistors) is fast approaching the atomic scale, resulting in a gulf between the computational efficiency required by data scientists and hardware capacity available from conventional computing based on the von Neumann architecture and binary operations.[1] Artificial electronic synapse (e-synapse) devices are necessary in order for the effective implementation of artificial neural networks (ANNs) in hardware / machine learning operations to occur.[2] Organic memristors can provide the functionality required to meet these computational demands by providing multi-level memory coupled with high-density integration, as well as possessing all of the advantages inherent to organic materials such as flexibility and biocompatibility.[3] Memristors are two-terminal resistive switches which can encode information in the form of programmable internal resistance, the evolution of which can be modulated by the history of its external stimuli.[4] Memristors offers much greater memory density than typical devices by enabling 'multi-bit' memory, as well as facilitating the co-location of memory and logic operations, overcoming the energy- and time-expensive separation between memory and computation execution.[5]

Herein we demonstrate a self-assembled analog resistive switching nanowire network with programmable multi-level memory based on 2,4-bis[4-(N,N-diisobutylamino)-2-6-dihydroxyphenyl]squaraine (SQ), a small-molecule organic semiconductor. The device shows the typical pinched hysteretic *I-V* loop of a memristor with gradual changes in conductance upon successive sweeps, akin to the synaptic weight update processes in the human brain. The memory retention is shown to decay to its original state within a relatively short time in the absence of external voltage application, which is satisfactory for neuromorphic computing applications such as online learning where the synaptic weight values can be stored elsewhere following the training process.[2] This time-dependence enables short-term plasticity functionality to be demonstrated (paired-pulse facilitation and post-tetanic potentiation). Potentiation and depression cycles are shown to exhibit linear and symmetric conductance tuning, a key requirement for implementation of neuromorphic computing. Furthermore, short-term memory to long-term memory conversion is demonstrated through repeated sequences of voltage pulses. Overall, SQ nanowire networks appear to present attractive properties that could enable the successful embedding of organic nanowire-based ANNs directly in hardware circuits.

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