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Neuromorphic-Inspired Behaviour in Core-Shell Nanowire Networks

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***Abstract*—** Engineering smart-materials with emergent properties requires designing and characterizing systems with desirable behaviours. Neuromorphic (brain-like) architectures require plasticity, where the strength of the connections and the time with which they decay can be modulated based on the magnitude and the repetition of the applied stimuli. This functionality is emulated in our complex nanowire network material through electrical resistive switching. The formation of nano-sized filamentary connections between overlapping wires across the network facilitates a controllable transition from a high resistance state to one (or more) lower resistance states with corresponding memory retention times. We report on the neuromorphic inspired behaviors that emerge from networks of metal nanowires coated with TiO_2 shells.

I. Introduction

There has been considerable interest in the use of nanomaterials for new types of nonvolatile memory technology, where the resistive switching action is controlled by the properties of both the electrodes and the dielectric materials that comprise these devices[1]. One highly desirable behaviour of neuromorphic systems is associative memory, memory that is stored and recalled by content rather than by address; such a device emulates biological memory rather than conventional digital memory and could act as inorganic synapses in brain-inspired neuromorphic hardware[2].

Recently, individual TiO_2 nanowires have shown memristive behaviour, where the device could retain a state of internal resistance based on the history of the applied voltage and current and could be programmed to hold multiple memory states[3]. Furthermore, single TiO_2 nanowires have exhibited a unique time-correlated associative learning response to heterogeneous optical and electrical stimuli[4]. To improve current response and insure switching occurs over nanoscale dimensions, a highly conductive metal nanowire was coated with a thin polycrystalline TiO_2 shell (40 nm) via solvothermal synthesis that yielded Ag@TiO_2 core-shell nanowires, as shown in the transmission electron microscope image of Fig. 1(a). Using Ag electrodes, it was found that *both* bipolar and unipolar resistive switching responses, collectively known as nonpolar resistive switching, could be selected by varying the magnitude of the current level used to activate the device. The memory retention time was intrinsically linked to the resistive switching regime, which allowed for a short-term retention time of up to 10^3 s in the bipolar state, and long-term memory (> 10^6 s) formation in the unipolar regime[5]. In this work, we report on the assembly of these core-shell nanowires into randomly orientated nanowire networks (NWN) (Fig. 1(b)).

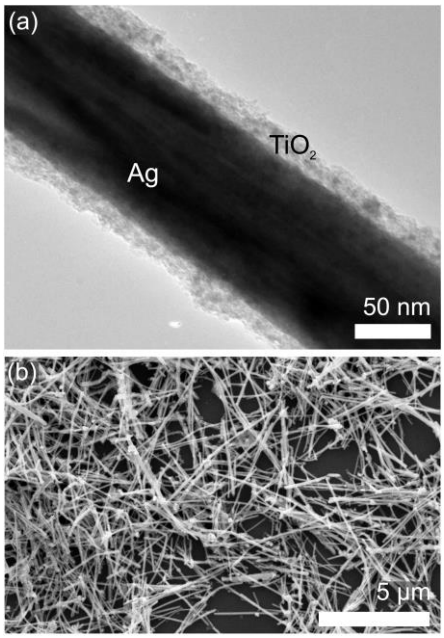

Fig. 1. (a) A high-resolution transmission electron microscope image of a Ag@TiO_2 core-shell nanowire. (b) A scanning electron microscope image of a core-shell nanowire network.

A NWN involves a random arrangement of nanowires on a substrate, such that its connectivity allows for at least one and in most cases multiple pathways between two opposing electrodes. NWNs are of immense technological interest due to their properties of high transparency, high porosity, flexibility, ease and low cost of fabrication[6]. The performance of any collective is controlled by the interactions between the individual components; these properties are not only defined by the material but augmented by the additional functionalities derived from the network, such as fault tolerance, self-selective pathways, and the decentralization of information [7]. We show that NWNs have the potential to become promising memristive architectures for neuromorphic applications due to their interconnectedness and the neurosynaptic-like behaviours at each of the junctions. Neuromorphic computers are expected to outperform conventional computing architectures at tasks which are natural to biological brains, such as self-learning, sensory processing, pattern recognition and motor control.

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