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Chalcogenide Microfiber Photonic Synapses

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Abstract: Optical axons and photonic synapses implemented using chalcogenide microfibers allow the generation and propagation of photonic action potentials which give rise to the demonstration of various neuromorphic concepts.

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Thus far, inorganic scalable neuromorphic systems and devices have been demonstrated using software and electronic configurations. However, as compared to biological systems based on organic axons and synapses, today's programmable inorganic computers are 6 to 9 orders of magnitude less efficient in complex environments. Simulating 5 seconds of brain activity takes 500 seconds and needs 1.4 MW of power [1,2,3,4]. Inspired by the emerging neuromorphic electronic systems and motivated by the potential of an all-optical cognitive platform, here we investigate and propose the use of amorphous chalcogenide microfibers as all-optical axons and synapses that exhibit brain-like functionality in the form of plasticity and data transmission in one scalable configuration.

Optical fibers provide a mature mass manufacturable technology that has given rise to the complex network of interconnected nodes transferring information around the planet. They have been realized in a range of functional optical and electronic materials including amorphous, crystalline and semiconducting compounds [5,6,7]. In this work we realise an optical axon and photonic synapse based on neuromorphic chalcogenide microfibers of the alloy gallium lanthanum oxysulphide (GLSO) with an outer diameter of 150 µm, with a transmission window from 550 nm to 7 µm (Fig. 1). As a proof-of-concept, we demonstrate a variety of neurophysiological phenomena in the optical regime mimicking communication protocols in the mammalian central nervous system, including temporal and spatial summation, excitatory and inhibitory post synaptic potentials, and short and long term plasticity.

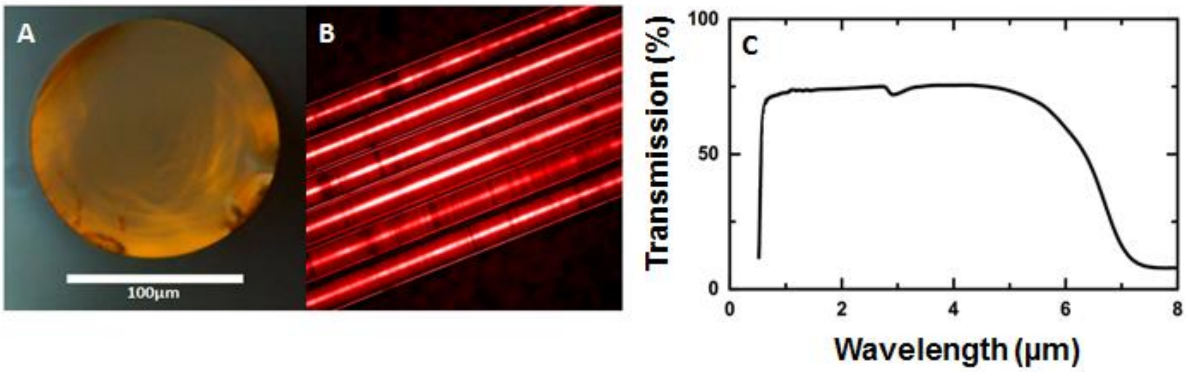

Figure 1: Optical microscopy image of (A) cross-section and (B) a bundle of gallium lanthanum oxysulphide microfiber (C) Optical transmission window of gallium lanthanum oxysulphide fibers.

Chalcogenide alloys are amorphous semiconducting media whose physical properties can be temporarily or permanently altered with light. Thanks to this, chalcogenide microfibers present an inorganic analogue of a biological neuron where signal propagation and processing is realised by optical confinement of light waves and photomodulation of their transmission properties, rather than by biochemical and electrical signal transduction. To implement an all-optical neuron in amorphous chalcogenide microfibers, we use photodarkening, which is a temperature dependent phenomenon that manifests itself in the form of a volatile (transient) and non-volatile (metastable) broadband attenuation in transparency and optical bandgap, brought about as a result of illumination with near or sub-bandgap light (Fig. 2). While the transient changes decay upon switching off the illumination, metastable photodarkening is non-volatile and reversible by annealing [8,9,10,11,12] providing the basis for short term and long term plasticity.

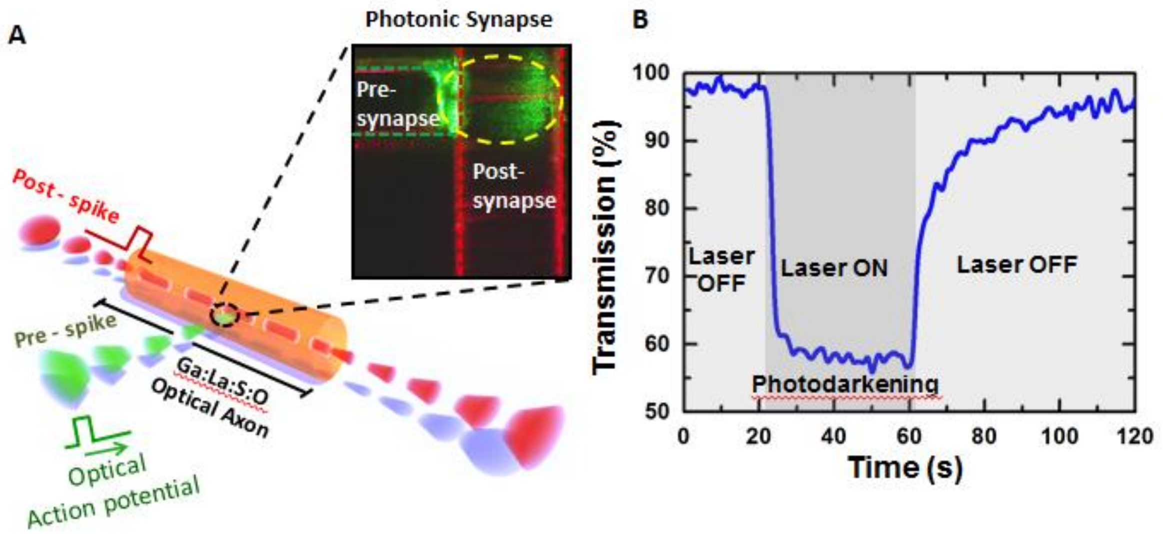

Figure 2: (A) The optical neuron transmits information through optical signals (laser pulses) that propagate along a gallium lanthanum oxysulphide fiber, and use photodarkening as a result of sub-bandgap light exposure at the photonic synapse (inset) to induce inhibitory and excitatory action potentials in the post-synaptic axon. (B) Photodarkening occurring upon exposure of the GLSO microfiber to sub-bandgap excitation (λ=532 nm, I=130 mW) within the period 20 to 60 s reduces transmission of guided light (λ=650 nm, I=10 mW) by ~40%.

Such neuromorphic chalcogenide microfibers have the potential to realise multichannel neuromorphic modules and systems configured anywhere from visible to mid-infrared wavelengths. This, along with implementation of short term and long term photonic memory, possible through inherent photoinduced properties of chalcogenide glasses, can enable truly neuromorphic devices operating on similar spatio-temporal principles as the human brain with ultrafast propagation speed, high bandwidth, and low thermal footprint.

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