Properties of 3D ZnO tetrapod networks as a material for neuromorphic hardware

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Physical systems serving as neuromorphic hardware must naturally exhibit nonlinearity, fading memory, high dimensionality, and multimodal responsivity – properties that conventional semiconductor technologies struggle to provide without significant energy overhead.

In this work, we investigate the memristive and optoelectronic dynamics of three-dimensional ZnO tetrapod networks (TNs) as a platform for next-generation neuromorphic and reservoir computing architectures. ZnO TNs combine a highly interconnected, disordered morphology with rich defect chemistry and strong light-matter interaction, enabling a unique interplay between electrical conduction, oxygen-mediated surface states, and persistent photoconductivity. Through comprehensive characterization – including I-V measurements, optoelectronic stimulation, and impedance spectroscopy with and without environmental isolation – we reveal a spectrum of nonlinear dynamical behaviours, slow relaxation processes, and stimulus-dependent conductance modulation that resemble synaptic and neuronal primitives. The networks exhibit analogue and history-dependent resistive switching, long-lived internal states, and tunable photo-induced conductance pathways, all emerging from the collective behaviour of thousands of junctions rather than engineered device stacks.

This intrinsic complexity positions ZnO TNs as a promising physical reservoir capable of processing temporal information directly at the material level, with potential for in-sensor computing, adaptive signal processing, and low-power edge AI. In greater detail, the ZnO TNs tend to behave as non-linear varistor-like elements with smooth, parabolic I-V characteristics. In the dark, they conduct only a few pA at 20 V and show a small I-V hysteresis with higher resistive states followed by lower resistive states and a time constant of a fraction of a second. Under UV light illumination (below ~ 400 nm) with low intensity, the output current increases drastically, almost up to 1 mA at 20 V. The I-V curves also evidence a slight analogical bipolar memristive effect with a low resistance state followed by a high resistance state. The UV on/off transients follow a bi-exponential decay with characteristic times of a few seconds and a longer component of several hundred seconds. The study establishes ZnO TNs as a scalable, stable, and multifunctional neuromorphic medium, bridging memristive physics with functional computation and opening pathways toward unconventional hardware implementations of reservoir computing.