Insect brain-inspired neuromorphic computing with nanoscale sensory neuron arrays

J. Azevedo(1), B. Jacob(1), J. Silva(1), J. B. Nieder(1), A. Mikkelsen(2), and B. Romeira(1)*

*bruno.romeira@inl.int

(1) INL - International Iberian Nanotechnology Laboratory, Av. Mestre José Veiga S/N, 4715-330, Braga, Portugal
(2) Department of Physics and NanoLund, Lund University, 22362, Lund, Sweden

Neuromorphic computing is facing major challenges in energy consumption, interconnects, and scalability, as communication between large numbers of artificial neurons requires complex wiring and significant power. Conventional electronic and photonic approaches still face limitations to combine within the same platform sensing, node nonlinearity, dense connectivity, low-energy operation, and compact device footprints [1]. Inspired by the insect brain [2], we explore nanophotonic spike-based sensing and computing using III–V semiconductor nano-optoelectronic devices that integrate optical sensing and neuron-like dynamics within a single compact hardware. Our goal is to bring intelligence closer to the source of data by combining sensory transduction, nonlinear processing, and temporal spike-based encoding in a single physical platform.

Here, we present a neuromorphic photonic micro- and nanopillar array sensory photoreceptor neuron platform based on semiconductor III-V photosensitive resonant tunnelling diode nanostructures [1]. In this approach, near-infrared optical input induces strong nonlinear negative differential resistance response and activates large-amplitude electrical spike burst oscillations. As a result, incoming analog optical stimuli are encoded into spatiotemporal oscillatory electrical signals, enabling simultaneous sensing, amplification, preprocessing, and temporal spike-like signal encoding within a single compact node, biomimicking the processing stages of light in the biological insect eye-brain. Further, under pulse-modulated illumination, the same device exhibits controlled excitation and inhibition of burst-firing patterns, reproducing neural-like oscillatory dynamics highly relevant to event-driven sensory computation. We also develop III–V nanoscale emitter and receiver arrays with ultra-violet and visible light polarization sensitivity to emulate photoreceptor neurons in insect vision circuits for robust and energy-efficient sensing and computation relevant for autonomous navigation systems [3].

This approach is of key relevance for neuromorphic computing since it supports integrated in-sensory-computing nodes with intrinsic nonlinear spike-based dynamics, instead of conventional architectures based on separate sensing and processing units. These advances pave the way toward low-power neuromorphic hardware for in-sensor computing, adaptive vision, and autonomous edge intelligent nanosystems.

Acknowledgements: European Innovation Council, project InsectNeuroNano (101046790).

[1] B. Romeira et al., Neuromorphic Comput. Eng., 3, 033001, 2023.

[2] T. Stone et al., Curr. Biol., 27, 3069-3085.e11, 2017.

[3] E. Gkanias et al., PLoS Comput. Biol.15, e1007123, 2019.