

Emerging vanadium dioxide memristor-based spiking concepts towards analog neuromorphic event sensing

Denis Flandre, Noémie Bidoul, Grégoire Brandsteert, Jean-Charles Delvenne, Thomas Ratier, Xi Zeng, Léopold Van Brandt

SWIMS ERC project, ICTEAM institute, UCLouvain, Louvain-la-Neuve, Belgium

Event-based detection has emerged as a solution to lower the data rate and energy consumption of sensor arrays, notably in the case of image sensors. However, to combine them with promising spiking neural networks (SNN) for event identification in internet-of-things edge nodes, digital interfaces and spike regeneration circuits are still required, leading to increased resource complexity and power consumption.

In our work, we first investigate how analog spikes could be generated within the sensors themselves towards direct interfacing with neuromorphic processors. We propose a specific implementation, based on vanadium dioxide (VO_2), a phase-change material that exhibits reversible metal-insulator transitions (MIT) at a temperature of about 70 °C. Insulator-to-metal transition (IMT) can also be triggered by applying a voltage across the VO_2 resistor exceeding a certain threshold value (V_{MIT}) and reversely when lowering the voltage below another metal-to-insulator threshold (V_{MIT}). The resulting I-V characteristics are typical of a memristor behavior, featuring a hysteresis in voltage-driven operation or a negative differential resistance (NDR) in current-driven mode.

These behaviors can be leveraged to design oscillators made of a single VO_2 memristor, a bias resistor or current source, and a capacitor. The properties of such oscillators have been measured as a function of VO_2 characteristics, temperature, bias current and capacitor value, and analyzed in terms of average frequency and cycle-to-cycle fluctuations, leading to a potential precision of about 0.1 °C on a hazard temperature threshold of about 45 °C. Similar studies have been carried out notably in EPFL (Switzerland) with respect to other stimuli such as electromagnetic or strain.

Secondly, encoding the sensed stimulus into the rate or frequency of the oscillator is not sufficiently energy-efficient. A better encoding can be achieved by sparse spikes or spike trains further used as input for the neurons and synapses of a SNN. The proposed VO_2 -based sensory neuron is reported to operate in this mode when biased below threshold, by exploiting intrinsic noise sources to generate stochastic spike bursts. Their temperature dependence has been measured and characterized. The statistics of the bursts have been observed to follow Poisson distributions, corresponding to more biologically-plausible signals.

Finally, we have adapted a physics-based memristor model to further analyse and discuss the experimental behaviors. This compact model could be used as a tool to design new sensors based on VO_2 memristor targeting ultra low-power consumption (sub-pJ per spike) and bio-plausible signals (towards event-based detection).

Acknowledgments: This work is fully supported by the European Research Council (ERC) under the European Union's Horizon AG research and innovation program (ERC-Synergy, SWIMS, 101119062) and the FRS-FNRS 'chargé de recherche' grant supporting Dr. Van Brandt. The authors thank the staff of the Winfab cleanroom and Welcome characterization platforms in UCLouvain for their support.