Local Activity Theory applied to Electro-Thermal Vanadium Dioxide Memristors: a Design Tool for Spiking Circuits.

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Vanadium dioxide (VO_2) is a compelling candidate for neuromorphic spiking neurons [1] thanks to its phase-change properties enabling an insulator-to-metal transition (IMT) near 68 °C. When current biased, two-terminal VO_2 devices can exhibit negative differential resistance (NDR) behavior in a certain I-V range and, under appropriate circuit conditions, generate spontaneous oscillations. Despite significant technological progress, a modelling framework to relate material properties to circuit-level behavior has mostly relied on hand-fitted analytical conductance models [2]. The present work demonstrates a fully data-driven flow from measured resistivity to Local Activity (LA) stability predictions [3] applied to the design of VO_2 spiking neurons.

We present an experimental and theoretical study of VO_2 electro-thermal memristors (typical geometry: length = 3 µm, width = 6 µm, thickness = 135 nm) characterised under current and voltage sweeps. Biasing the device with a current source and measuring its voltage drop with an oscilloscope (illustrated Fig. 1a)) shows that the NDR curve measured by the DC source practically corresponds to an average of spontaneous self-voltage oscillations, predicted theoretically by Brown et al. [4].

Building on this electro-thermal compact model and LA framework, we derive all stability parameters directly from the experimental electrical resistivity ρ(T) and thermal conductivity κ(T) curves in a data-driven approach. The model reproduces the measured current- and voltage-driven I–V DC characteristics of a reference device. Such an approach allows us to translate device operation regimes such as locally passive (LP), active (LA) and edge-of-chaos (EOC) into bifurcation and spiking criteria at the circuit level, e.g., depending on parallel capacitance (see Fig. 1b)). Practically, to sustain stable spiking behavior the device must be at EOC and satisfy the Hopf bifurcation criteria depending on the rest of the circuit. It is then used to assess the oscillation condition for different parameters, thereby guiding the practical design and integration of VO_2 memristors. Fig 1.b) depicts one of the core results: the oscillating mapping of a typical device depending on its operating current and temperature for a fixed 1.5 nF parallel capacitance. The boundary of the oscillation region (frequency range: 100–900 kHz) is influenced by the effective parallel capacitance of the system, as the oscillating region is smaller than the EOC area. It highlights an operating temperature and current window to ensure spike generation, while the framework accounts for the material properties and device geometry.

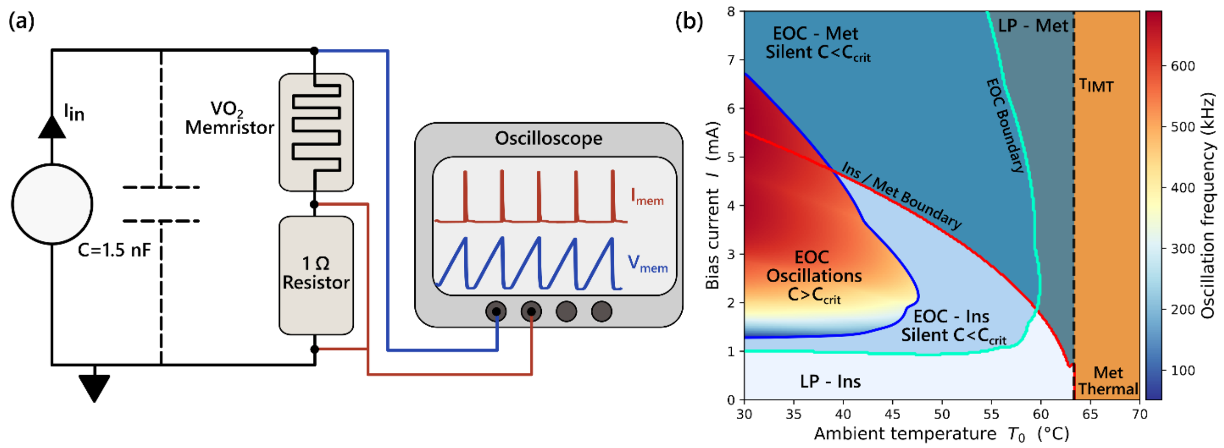

Figure 1: (a) Experimental set-up with a device measured in the NDR region producing spikes with a system total parallel capacitance C = 1.5 nF. (b) Device behavior mapping showing which parameter combinations (temperature/current) can lead to a spiking regime, and the evolution of frequency in the oscillating-EOC region.

References

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