Temperature-Sensitive Spiking Neurons Implemented with Microfabricated Vanadium Dioxide Memristors

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Biologically-inspired sensory neurons implemented with phase-change materials [1] like *vanadium dioxide* (VO_2) [2] are able to encode the perceived information into spikes in the time domain. Operating in the analog world without digital conversions and memories, exceptional energy efficiency is promised for these systems compared to ultra-low-voltage CMOS architectures [1].

At UCLouvain, VO_2 *memristors* exhibiting reversible metal-insulator transitions (MIT) have been successfully microfabricated [2]. The voltage- and current-driven static characteristics of one typical VO_2 memristor are shown in Figure 1(a). A circuit made of a VO_2 memristor (Figure 1(b)) driven by an appropriate current source (e.g. a MOS transistor) can leverage the MIT to generate continuous voltage spikes on the output capacitor shaped by a charge-discharge process (Figure 1(c)).

We have distinguished between two operating regimes of the neuron, corresponding to two distinct configurations of the memristor. Firstly, when the device is biased in the negative differential resistance (NDR) region (Figure 1(a)), the neuron behaves like a *relaxation oscillator* with a stable limit cycle as its steady state. In this configuration, the stimulus (here, temperature) is encoded in the spike duration or, equivalently, the spike frequency [2]. Secondly, to achieve higher energy efficiency and more biologically plausible *excitable* behaviour towards event-based sensing and computing, another less studied *stochastic bursting* regime [3], is experimentally reported in Figure 2. While preliminary analyses of the spike and burst statistics suggest that the circuit noise likely dominated by the intrinsic stochasticity of the VO_2 memristor induces a transient escape from a stable equilibrium to a limit cycle the bursting regime stills awaits further mathematical modelling.

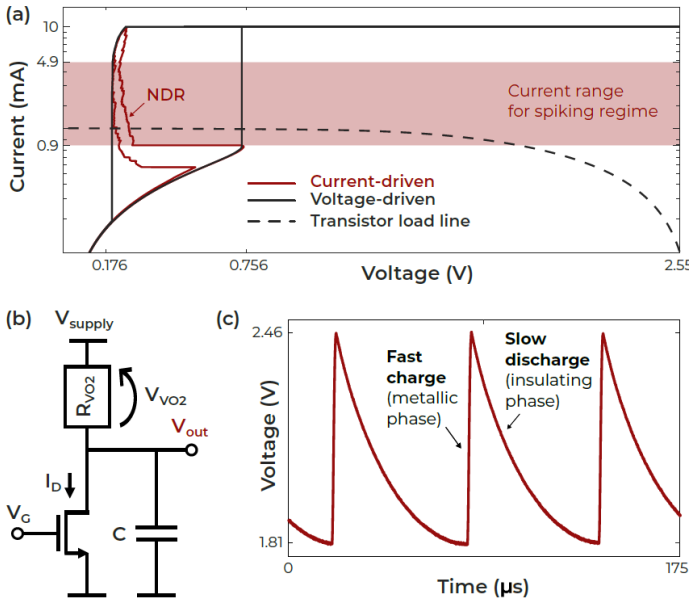

Figure 1. (a) Static characteristics of a microfabricated VO_2 memristor in both voltage- and current-driven modes. (b) Circuit schematic used to trigger the spiking sensory neuron. (c) Experimentally measured spikes at 41 ºC (V_{supply}= 2.55 V, I_D = 1 mA, C = 33 nF) when the neuron operates as a relaxation oscillator, suggesting that the studied system has a closed orbit that is a limit cycle. Reproduced from [1].

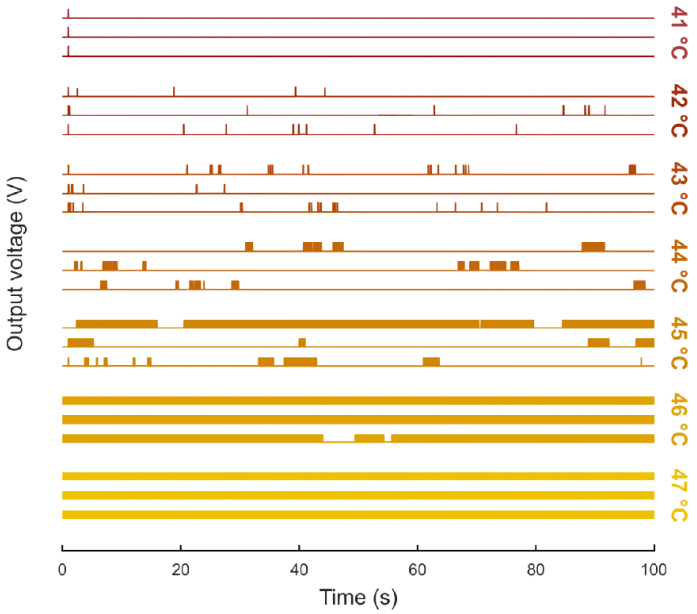

Figure 2. Evolution of the stochastic bursting behaviours from 41 to 47 ºC (V_{supply}= 4.5 V, I_D = 0.75 mA, C = 33 nF). Three 100 s-long traces, sampled at 100 kHz, were recorded for each temperature. Adapted from [3].

[1] R. Carboni and D. Ielmini, *Advanced Electronic Materials*, **5**(9), 1900198, 2019

[2] N. Bidoul et al,. *Proc. of IEEE ESSDERC,* 2023

[3] N. Bidoul . *Proc. of Neuronics Conference,* 2023