

Tuning the stochasticity of VO₂ neurons firing-threshold through grain size engineering

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Threshold firing behavior in VO₂ neurons is enabled by their Insulator-to-Metal transition (IMT), which can be triggered electrically by applying a voltage across a micro-scaled VO₂ resistor. However, akin to biological neurons, the threshold voltage V_{IMT} at which firing occurs varies from one excitation to another, due to inherent stochasticity in the relaxation process [1].

Requirements on the stochastic behavior of VO₂ neurons depend on the target application. When used in stochastic neural networks [2], a certain amount of stochasticity is desirable, as it allows to mimic particular behaviors of biological neurons such as probabilistic spiking or stochastic resonance [3][4]. In opposition, when used as sensory neurons, stimulus power is encoded in spike rate [5][6][7][8] (e.g. through modulation of the firing threshold) : in this case, stochasticity can deteriorate the limit of detection and should thus be minimized. In each type of application, the target neuron performance (respectively spiking probability tuning range or sensitivity) is constrained by the inherent stochasticity. However, there has been sparse research regarding which underlying material properties of the VO₂ thin film impact the stochastic behavior.

Bridging this gap, our work demonstrates the first experimental evidence that grain size in polycrystalline VO₂ films greatly affects the neuron firing-threshold stochasticity. We fabricate VO₂ resistors with identical sub-micron dimension, from two sputtered films with 10-fold difference in grain size (obtained through control of annealing temperature). We then compare the variations of their V_{IMT} threshold voltage over 400 cycles of voltage-driven DC sweeps. The small-grain resistor shows remarkably few variations, with a clear Gaussian distribution. The second resistor, whose grain size becomes comparable to its length, has a more pronounced stochastic behavior with a V_{IMT} distribution fitted by a Gaussian mixture, whose main component shows a 4 to 10-fold increase in standard deviation compared to our first device.

We attribute these observations to the filamenting nature of the transition, during which only a subset of grains inside the resistor actually become metallic. The phenomenon percolates from a few “seed” grains which may change from cycle to cycle, yielding different filaments [9][10]. In small-grain devices, these filaments involve larger numbers of grains, averaging out their individual characteristics. In large-grain devices, this number of grains decreases, and their anisotropy yields larger variations of firing threshold.

We thus propose the first design guidelines to significantly tune VO₂-neurons stochasticity, by fabricating films with different grain sizes, each best suited for specific neuromorphic applications.

References

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