Resistive switching memories for spiking neural networks

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Resistive switching memory technologies (RRAM), also named as memristive devices, are graining increasing attention for implementing unconventional computing concepts, such as in-memory and brain-inspired computing [1]. RRAMs are very promising because of low power consumption, scalability down to nm scale, CMOS compatibility and capability to support in-memory computing in neural networks, then overcoming the limit of the von-Neumann computing architecture. Moreover, RRAMs can serve as dynamic elements exhibiting useful neuromorphic functionalities such as analogue control and evolution in time of their conductance values as a function of input stimuli. Today, RRAMs are becoming promising compact building blocks in hardware spiking neural networks (SNNs) to reproduce the synaptic or neural functions, and their rich dynamics is used to build circuits and systems able to processes information with temporal structure and compute over multiple time scales, mimicking the brain functionality. In the medium to long perspective, RRAMs can substitute and/or complement CMOS circuits in future neuromorphic chips [1-3], also towards low-power computing systems for edge applications, such as the ones relying on smart analysis of sensory signals in real time.

In this work, we will first introduce the current state of the art and role of RRAMs and memristive systems in neuromorphic computing with focus on materials systems and types of devices under investigation to implement the synaptic and neural functions; and we will discuss device requirements versus SNNs implementation. In the second part, we will show our recent results in the field of RRAM devices, featuring a metal/insulator/metal stack device structure, for neuromorphic applications. We will show how RRAMs, depending on the used material stacks and programming strategies, are used to implement neuromorphic functionalities, such as analogue dynamics response to input stimuli [2-5], and controllable stability of the device resistance states over various time scales. We will also show how memristive devices can function as volatile or non-volatile dynamic memory elements mimicking the short/long term plasticity of biological synapses. As example, we engineered both analogue non-volatile HfO_x-based RRAM as synaptic nodes in SNNs, and Ag/SiO_x- or Ag/Al_2O_3/SiO_x-based devices with tunable retention properties (from µs to tens of seconds), and exhibiting a conductance modulation as a function of trains of input spikes.

To summarize, we will show how diverse types of RRAMs, relying on different material stacks and mechanisms, can be engineered for neuromorphic computing with focus on SNNs hardware implementation. We will discuss on materials stacks, device characteristics and underlying physics, and finally we will further analyse how to exploit device properties in hybrid CMOS/RRAM neural networks through system-level simulations [6-8].

References

1. D. V. Christensen et al., Neuromorph. Comput. Eng. **2** 022501(2022)
2. E. Covi, R. George, J. Frascaroli, S. Brivio, C. Mayr, H. Mostafa, G. Indiveri, S. Spiga, Journal of Physics D: Applied Physics **51**, 344003 (2018)
3. S Brivio. S. Spiga, D. Ielmini, Neuromorph. Comput. Eng. **2**, 042001 (2022)
4. T. Wang, S. Brivio, E. Cianci, C. Wiemer, M. Perego, S. Spiga, M. Lanza, ACS Applied Materials & Interfaces **14,** 24565 (2022)
5. F. Vaccaro, S. Brivio, S. Perotto, A.G. Mauri, S. Spiga, Neuromorph. Comput. Eng. **2**, 021003 (2022)
6. S Brivio, D.R.B. Ly, E. Vianello, S. Spiga, Frontiers in Neuroscience **15**, 580909 (2021)
7. S Brivio, D. Conti, M. V. Nair, J. Frascaroli, E. Covi, C. Ricciardi, G. Indiveri, S. Spiga, Nanotechnology **30**, 015102 (2019)
8. E. Gemo, S. Spiga, S. Brivio, Front. Neurosci. **17,** 1270090 (2024).

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