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The Emergence of Memory at the Nanoscale

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Abstract : Memcomputing is a computational paradigm that combines information processing and storage on the same physical platform. Key elements for this topic are devices with an inherent memory, such as memristors, memcapacitors, and meminductors. Despite the widespread emergence of memory effects in various solid systems, a clear understanding of the basic microscopic mechanisms that trigger them is still a puzzling task. We report basic ingredients of the theory of solid-state transport, intrinsic to a wide range of mechanisms, as sufficient conditions for a memristive response that points to the natural emergence of memory. This emergence should be discernible under an adequate set of driving inputs, as highlighted by our theoretical prediction and general common trends can be thus listed that become a rule and not the exception, with contrasting signatures according to symmetry constraints, either built-in or induced by external factors at the microscopic level. Explicit analytical figures of merit for the memory modulation of the conductance are presented, unveiling very concise and accessible correlations between general intrinsic microscopic parameters such as relaxation times, activation energies, and efficiencies (encountered throughout various fields in Physics) with external drives: voltage pulses, temperature, illumination, etc. These building blocks of memory can be extended to a vast universe of materials and devices, with combinations of parallel and independent transport channels, providing an efficient and unified physical explanation for a wide class of resistive memory devices that have emerged in recent years. Its simplicity and practicality have also allowed a direct correlation with reported experimental observations with the potential of pointing out the optimal driving configurations. The main methodological tools used to combine three quantum transport approaches, Drude-like model, Landauer-Buttiker formalism, and field-effect transistor emulators, with the microscopic characterization of nonequilibrium dynamics. Both qualitative and quantitative agreements with available experimental responses are provided for validating the main hypothesis. This analysis also shades light on the basic universality of complex natural impedances of systems out of equilibrium and might help pave the way for new trends in the area of memory formation as well as in its technological applications.

Keywords : memories, memdevices, memristors, nonequilibrium states
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