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Big data processing and large-scale computational needs will soon be limited by local on-chip power dissipation of available semiconductor technologies. Moreover, the increasing demand for information processing will likely create an unsustainable exponential growth in global energy consumption. This will slow down Moore's law and will require the holistic rethinking of computation all the way from unique materials, unconventional devices, and functionalities to novel systems and architectures. Neuromorphic systems based on conventional CMOS technologies have demonstrated promise in providing brain-like functionalities such as pattern recognition, adaptive learning, and complex sensing. However, their future potential is limited by unsurmountable issues, intrinsic to the materials properties of conventional semiconductors. Quantum materials and devices are likely to serve as a revolutionary, energy efficient, next-generation computational platform for developing a machine that emulates a biological brain. This field is at a stage where it could greatly benefit from further basic research in all aspects of this problem. This Special Topic issue is dedicated to appraising the field's state of the art and showcasing new, potentially revolutionary ideas.

Further understanding of the properties of quantum materials, the effect of defects and their ultimate effect on devices and systems must be understood using a combination of techniques that include *ab initio* theoretical calculations combined with state-of-the-art synthesis and nanoscale structural, electrical, magnetic, and optical characterization. A comprehensive, quantitative, interdisciplinary study of relevant materials under high (electrical, thermal, magnetic, and physical) stresses is important.[1] Modern synthesis and characterization tools are at a stage when they can provide detailed control and information regarding the structure of materials and their effect on their physical properties.

Armed with a thorough understanding of the materials properties, new design concepts are being developed that go beyond conventional semiconductor devices either based on the charge[2] or even the spin[3,4] of the electron. For instance, Mott physics provides the means to emulate brain inspired devices. "Neuronal" devices accumulate "metal phase" and modulate the conduction by metallic filamentary growth, while synaptic devices encode a memory state by moving and modulating the concentration of defects (e.g., oxygen vacancies).[5,6] Broadly speaking, memristive phenomena are yielding fascinating design concepts for memory,[7] networks,[8] and neuro-sensors when combined with light-sensitive oxides.[9] Synaptic behavior, which requires plasticity in the response function of a material, can be achieved in polymer-gated transistors showing multiple functionalities,[10] as well as in photonic[11] and magnetoelectric systems.[12] Alternatively, spin-based devices take advantage of prominent nonlinearities in the magnetic responses of quantum materials. Nanoscale magnetic phenomena can be harnessed to fabricate nanowires,[13] while magnetic anisotropies are proposed to train networks,[14] and optomagnetic neural networks can be tailored to produce low-dissipation networks thanks to the low-energy plasticity and non-volatility of magnetic properties.[15] Superconducting Josephson devices can generate time-dependent responses that mimic neuronal spiking and synaptic and dendritic trees.[16] These and many other physical phenomena are being considered as pathways to mimic the majestic processes carried out by the brain such as reservoir computing[17] and in-memory computing.[18] However, in order to incorporate these into functional devices, it is important to understand the ultimate physical limits of these phenomena, including what are the minimal sizes, shortest times, or the closest physical proximity allowed by the physics of the materials and devices; all these are directly relevant to scaling issues.

Biological neurons and synapses display emergent behavior, which is at the heart of their complexity and unparalleled efficiency. The emergent properties of quantum materials and their nonlinearities exhibit numerous self-organizing principles, which provide a multiplicity of static and dynamic states useful to emulate complex neural devices and networks.[19] In particular, metastability produced by complex energy landscape of the quantum system offers the potential for a variety of multiple memory states, fine tuning of critical behavior[20] and emergence of novel collective phenomena.[21] In order to approach the challenge of creating a brain-like machine, it is critical to consider the network in which the devices exist. Adapting Herbert Kroemer's statement to bio inspired neuromorphic computing, "the network is the system."

This Special Topic issue of *Applied Physics Letters* is dedicated to address some of the important issues outlined above and hopefully will serve as a future springboard for further work in the field.

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