文章编号: 1000-324X(2023)04-0365-02　　**DOI:** 10.15541/jim20231000

神经形态器件及其类脑计算应用

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在传统冯•诺依曼计算机中，中央处理器和存储器分离，数据吞吐量受到很大限制。因此，传统计算在处理非结构化数据时，其能量效率很难进一步提高。同时，传统 CMOS 器件的尺寸已接近物理极限，很难延续摩尔定律，这进一步限制了计算机的性能提升。为了在“大数据”时代提高计算系统的性能，必须改变计算机的计算范式。人类的大脑是一台高效、高容错和超低功耗的生物超级计算机。神经形态工程从生物大脑和感觉神经系统中汲取灵感，有望显著降低模式识别和决策判断等智能感知和计算任务的能耗和设备成本。

从底层出发研制具有生物突触/神经元功能的新概念器件对于构建神经形态系统和研制真正意义上的“类脑芯片”意义十分重大，已经引起世界各国政府、企业和高校的广泛关注。近十余年来，基于忆阻效应的神经形态材料与器件取得了诸多重要进展：在材料技术方面，从无机物到有机物，从传统材料到量子材料，从铁电材料到铁磁材料，从体材料到低维材料等，都展示出各自独特的神经形态特性；在器件功能方面，忆阻器可模拟的突触可塑性功能越来越多，已不再局限于突触模拟，还能够模拟神经元功能，这为实现全忆阻器神经形态电路创造了可能性。最新研究表明，以电解质、离子凝胶、铁电介质等薄膜为栅介质的晶体管比两端突触器件更加适合构建复杂神经网络。除人造突触器件之外，类脑计算系统还需要能够模拟具有生物神经元信息处理功能的神经形态器件。与此同时，柔性神经形态器件在下一代可穿戴系统、软机器人和神经修复技术领域具有重大应用价值。为了实现上述目标，需要在单个器件上实现简单的突触行为，并构建具有多种感知功能的仿生器件和系统。当神经形态器件被集成加工成阵列时，经典的机器学习任务如加速向量矩阵乘法、信息编码和数据分类便可以实现。

尽管神经形态器件及其类脑计算领域的研究已经取得了长足进步，但是实现低功耗类脑感知与计算功能依然面临巨大的挑战。我应《无机材料学报》编辑部邀请担任特邀编辑，以“神经形态材料与器件”为主题组织出版专栏。期待更多的中国科研人员投入该研究领域，通过合作共同推动神经形态材料与器件从基础研究到应用开发的快速发展，期待不久的将来实现神经形态器件类脑计算的商业化应用。

Neuromorphic Devices for Brain-like Computing

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In the traditional von Neumann computer, the data throughput is greatly limited due to the separation of the CPU and memory. Therefore, it is difficult to further improve the energy efficiency of traditional computer when dealing with unstructured data. At the same time, the size of traditional CMOS devices is approaching the physical limit, and it is difficult to continue Moore's law, which also limits the performance improvement of computers. To improve the performance of computing systems in the so-called "big data" era, the computing paradigm of computers must be changed. Our brain is a biological supercomputer with high efficiency, high fault tolerance and ultra-low power consumption. Neuromorphic engineering draws inspiration from biological brain and sensory nervous system, and is expected to significantly reduce the energy consumption and device cost of intelligent perception and computing tasks such as pattern recognition and decision judgment.

The development of new-concept devices with biological synaptic/neuronal functions from the bottom is of great significance to the construction of neuromorphic system and the development of a real "brain like chip". The research of neuromorphic devices and brain-like computing has attracted wide attention from governments, enterprises and universities around the world. In the past ten years, many important advances have been made in neuromorphic devices based on memristor effect. In terms of material technology, from inorganic to organic materials, from conventional materials to quantum materials, from ferroelectric materials to ferromagnetic materials, from bulk materials to low-dimensional materials, *etc*., all show their unique neuromorphic characteristics. In terms of function, memristors can simulate more and more synaptic plasticity functions, and are no longer limited to synaptic simulation, but also can simulate the function of neurons, which creates the possibility for the realization of the neural morphology circuit of full memristors. Recent studies have shown that transistors with electrolyte, ionic gel, ferroelectric and other thin films as the gate dielectrics are more suitable for constructing complex neural networks. In addition to artificial synaptic devices, brain-like computing systems also need neuromorphic devices that can simulate the information processing function of biological neurons. In addition, flexible neuromorphic devices have great application value in the field of next generation wearable systems, soft robots and nerve repair technology. In order to achieve this goal, we need to realize simple synaptic behavior on a single device, and build bionic devices and systems with multiple sensing functions. When neuromorphic devices are integrated and processed into arrays, classical machine learning tasks such as accelerating vector matrix multiplication, information encoding and data classification can be realized.

Although the research of neuromorphic devices and brain-like computing has made great progress, the realization of low-power brain-like perception and computing still faces great challenges. At the invitation of the editorial office of *Journal of Inorganic Materials*, I have served as the contributing editor and organized publication of the theme “*Neuromorphic Materials and Devices*”. It is expected that more Chinese researchers will invest in this research field, jointly promote the rapid development of neuromorphic devices from basic research to application development through cooperation, and realize the commercial application of neuromorphic device brain-like computing in the near future.

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