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EDITORIAL

Editorial: Focus issue on 2D materials for neuromorphic computing

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The aim of neuromorphic computing is to mimic synapses, dendrites and neurons in the brain, as well as their associated connected networks, to perform a variety of complex tasks, including sensing, computing and perception, sometimes by directly utilizing the physical properties of materials. Their functionality diversity and performance highly depend on the use of materials. Compared to conventional materials, 2D materials exhibit many unique physical properties and the research of 2D materials has reshaped the field of neuromorphic computing.

This special issue presents some of the innovations in using devices based on 2D materials to emulate biological synapses or generate noise injection to hardware neural networks. The issue also provides a comprehensive analysis of recent advances in the exploitation of the unique physical properties of 2D materials for neuromorphic computing. These innovations and analysis may serve as a useful guide to further advance 2D materials for practical applications. This special issue includes two research articles and four review articles, with their contents briefly summarized in the following paragraphs.

In Du *et al* [1], they proposed to use the $1/f$ noise generated in a 2D semiconductor MoS_2-based transistor to suppress overfitting in a multiplayer perceptron and long short-term memory. Using a simulation method, they showed that $1/f$ noise and Gaussian noise exhibit a similar performance in the multilayer perceptron. Furthermore, they demonstrated that the intrinsic long-range dependence of $1/f$ noise enables a better performance for long short-term memory than the Gaussian noise. The results of this paper may provide an alternative solution to improving the performance of hardware neural networks.

In Huang *et al* [2], chemical vapor deposition (CVD) -grown 2D MoS_2 films were used to fabricate an artificial electronic synapse, in which ion migration in the gate terminal was employed to modulate the conductance of the device. In this way, they realized emulation of synaptic functions, such as paired-pulse facilitation, spike-rate-dependent plasticity, spike-duration-dependent plasticity and spike-number-dependent plasticity. Due to the high sensitivity in response to ionic gating, a low-power consumption as small as 33.5 fJ per spike was demonstrated with this artificial synapse. This paper provides a promising pathway toward the future development of low-power and multifunctional neuromorphic systems.

In Qian *et al* [3], the recent advancements in ferroelectric devices and neuromorphic computing devices based on 2D organic crystals were reviewed. To elaborate the connection between the characteristics of 2D organic materials and their microstructures, they provided an overview of the synthesis strategies for large-scale, high-quality and monolayer 2D organic crystals. Furthermore, by examining the unique physical properties of these 2D organic crystals, they demonstrated how these properties can be used to design ferroelectric non-volatile memory devices, a promising type of neuromorphic computing device. The challenges and associated research prospects with the use of 2D organic crystals for near-sensor and in-sensor computing were also discussed.

In Wang *et al* [4], 2D materials for artificial synapses toward practical applications were reviewed. Artificial synapses based on 2D materials have remained at device level. It remains in doubt whether the characteristics of these artificial synapses can meet the requirements for practical applications, although they exhibit promising performances as individual devices. To evaluate the readiness of 2D synapses for practical applications, the authors provided a comprehensive and quantitative analysis of the impact of limited precision, nonlinear weight update, and intrinsic variation in the device on the accuracy, power and area of hardware deep neural networks. This review article provides an important guide for the development of 2D synapses for accurate online training and inference in the future.

In Chen *et al* [5], the recent progress in ferroelectric memory devices based on 2D materials has been highlighted for potential applications in neuromorphic computing. Ferroelectric memories using charge polarization of 2D materials have attracted intensive research interest over the past decade due to their unique properties that are inaccessible in conventional materials. The authors provided an overview of the merits of 2D two- and three-terminal architectures for ferroelectric devices reported to date, and discussed the challenges associated with the precise characterization of 2D ferroelectric materials and large-area growth of high-quality 2D materials. This review article provides some useful perspectives for achieving high-performance 2D ferroelectric memory devices.

In Zhang *et al* [6], the working mechanisms and device geometries of 2D materials as well as their associated heterostructures used for neuromorphic computing devices were summarized. Specifically, they explained how these materials can be used for artificial visual, tactile and auditory functions at the levels of both individual devices and arrays. Furthermore, they discussed the remaining important issues, such as the wafer-scale synthesis of high-quality and uniform 2D materials, compatibility with traditional CMOS fabrication processes and high-density integration of hardware neural networks. This review paper will deepen our understanding of the application of 2D materials and their heterostructures to the design of neuromorphic computing devices.

We hope this collection provides new insights into the advantages of using unique physical properties of 2D materials for neuromorphic computing.

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