Charge-Modulated Conductance and Synaptic Behavior in Access-Region WSe_2/*h*-BN/Gr van der Waals Floating-Gate Transistors for Nonvolatile Memory

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***Abstract*—Neuromorphic hardware requires nonvolatile memory and continuously tunable conductance to emulate synaptic plasticity in biological neural systems. Here, we report a van der Waals floating-gate field-effect transistor (FGFET) based on WSe_2/ hexagonal boron nitride (*h*-BN)/ graphene (Gr) heterostructure and systematically investigate its memory and synaptic characteristics. Charge trapping in the Gr floating gate produces a pronounced memory window, enabling stable and nonvolatile modulation of channel conductance. Under gate-voltage pulse stimulation, the device exhibits excitatory and inhibitory postsynaptic current (EPSC/IPSC)-like responses, with conductance states gradually tuned by pulse amplitude, number, and duration. These results demonstrate that the WSe_2/h-BN/Gr floating-gate platform is a promising candidate for neuromorphic synaptic applications.**

***Keywords*—neuromorphic devices; access region; van der Waals floating-gate transistor; synaptic plasticity; excitatory and inhibitory postsynaptic current.**

I. Introduction

The increasing demand for data-intensive and parallel computation has exposed fundamental energy-efficiency limitations in conventional von Neumann architectures due to the physical separation of memory and processing units. In contrast, biological synapses inherently integrate signal transmission and information storage within a single structural unit, inspiring the development of neuromorphic hardware capable of emulating synaptic functionality at the device level [1, 2].

Two-dimensional (2D) materials offer a compelling platform for developing varied neuromorphic devices owing to their atomic thickness, clean van der Waals interfaces, and tunable electronic properties [3]. In particular, floating-gate architectures incorporating Gr and layered semiconductors enable charge-storage-mediated modulation of channel conductance without continuous power consumption [4]. Based on this concept, we design and fabricate a WSe_2/ *h*-BN/ Gr van der Waals FGFET to investigate nonvolatile memory behavior and synaptic plasticity within a single electronic device.

II. Materials and Methods

Each of the 2D materials, including Gr, *h*-BN, and WSe_2 flakes, was mechanically exfoliated and sequentially assembled onto a SiO_2/Si substrate (300 nm SiO_2) through van der Waals stacking using a dry-transfer technique (Fig. 1). Source and drain electrodes were defined by electron-beam lithography. Electrical characteristics were performed using a Lakeshore cryogenic probe station coupled with a Keysight B1500A semiconductor parameter analyzer.

III. Results and Discussion

The transfer characteristics (Fig. 2(a)) of the WSe_2/*h*-BN/Gr FGFET exhibit a pronounced memory window (~90 V threshold shift), indicating efficient charge injection through the *h*-BN tunneling layer and effective charge storage in the Gr floating gate [5]. The linear output characteristics (Fig. 2(b)) at low drain bias indicates good ohmic contact, ensuring stable carrier transport and reliable operation.

To further evaluate synaptic functionality, pulse-response measurements were conducted. Under gate-voltage pulse stimulation, the device generates EPSC/IPSC-like transient responses, driven by charge trapping/detrapping in the floating gate. The channel conductance can be continuously tuned by varying pulse amplitude, duration, and number [6]. Furthermore, the conductance state can be systematically tuned by adjusting the pulse amplitude, pulse number, and pulse duration, leading to gradual and history-dependent evolution of the channel current. Such progressive and analog conductance modulation closely resembles synaptic weight updates in biological neural networks, demonstrating the capability of the floating-gate architecture to emulate spike-dependent synaptic plasticity.

IV. Conclusion

The WSe_2/*h*-BN/Gr van der Waals FGFET effectively integrates nonvolatile memory and synaptic functionality, highlighting its suitability for neuromorphic computing systems. Future work aims to extend functionality toward optoelectronic synapses via optical excitation.

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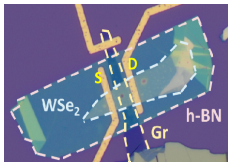

Fig. 1. Optical microscopy image of the fabricated WSe_2/*h*-BN/Gr FGFET.

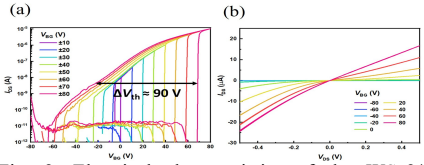

Fig. 2. Electrical characteristics of the WSe2/ h-BN/Gr FGFET. (a) Transfer curves at various VDS. (b) Output characteristics.