Graphene-Based Bidirectional Neural Interfaces for Full-Bandwidth Brain Monitoring

Anton Guimerà-Brunet

Institut de Microelectrònica de Barcelona, IMB-CNM (CSIC), Esfera UAB, Bellaterra 08193, Spain

Centro de Investigación Biomédica en Red en Bioingeniería, Biomateriales y Nanomedicina (CIBER-BBN), Madrid 28029, Spain

anton.guimera@csic.es

Flexible neural interfaces based on graphene solution-gated field-effect transistors (gSGFETs) have emerged as a powerful technology for brain interfacing. Over the past decade, these devices have been developed, optimized, and in vivo validated, demonstrating their ability to overcome the intrinsic limitations of passive metal electrodes and to capture the full spectrum of brain activity, thereby enabling new avenues for studying neural dynamics[1,2].

Recent advances include multimodal platforms that integrate transparent gSGFET arrays with cerebral blood-flow imaging, allowing simultaneous DC-coupled electrophysiology and haemodynamic monitoring. This combination provides mechanistic insight into cortical spreading depolarizations (CSDs), a key driver of secondary injury in stroke, and reveals how CSD waveform morphology and duration reflect local tissue viability[3].

Beyond recording, bidirectional graphene interfaces have been realized by monolithically integrating gSGFETs with high-charge-injection nanoporous graphene electrodes, enabling high-precision stimulation together with artefact-resilient, full-bandwidth recordings for closed-loop neuromodulation. These hybrid platforms maintain robust performance during high-frequency stimulation while preserving the fidelity of infraslow and LFP recorded signals.

A critical step toward clinical translation involves ensuring compliance with electrical-safety and regulatory standards. Frequency-division-multiplexing (FDM) architectures are being developed to support high-density brain-activity mapping while providing the protections necessary to limit patient leakage currents and guarantee isolation and fault tolerance [4,5]. These system-level strategies enable scalable, high-channel-count clinical interfaces while preserving the intrinsic advantages of graphene transducers, paving the way for safe implantation in human neurophysiology.

References

[1] A. Bonaccini Calia et al., “Full-bandwidth electrophysiology of seizures and epileptiform activity enabled by flexible graphene microtransistor depth neural probes,” Nature Nanotechnology, vol. 17, no. 01041, pp. 301-+, 2022

[2] E. Masvidal-Codina et al., “High-resolution mapping of infraslow cortical brain activity enabled by graphene microtransistors,” Nature Materials, vol. 18, no. 3, pp. 280-+, 2019.

[3] J. M. Zhang et al., “Concurrent functional ultrasound imaging with graphene-based DC-coupled electrophysiology as a platform to study slow brain signals and cerebral blood flow under control and pathophysiological brain states,” Nanoscale Horizons, vol. 9, pp. 544–554, 2024

[4] R. Garcia-Cortadella et al., “Switchless Multiplexing of Graphene Active Sensor Arrays for Brain Mapping,” Nano Lett., vol. 20, no. 5, pp. 3528–3537, May 2020

[5] J. Cisneros-Fernandez et al., “A 1024-Channel 10-bit 36-W/ch CMOS ROIC for Multiplexed GFET-Only Sensor Arrays in Brain Mapping,” IEEE Transactions on Biomedical Circuits and Systems, pp. 1–1, 2021