Encapsulation and protection strategies for graphene-based solution-gated field-effect transistors towards high performing neural recording

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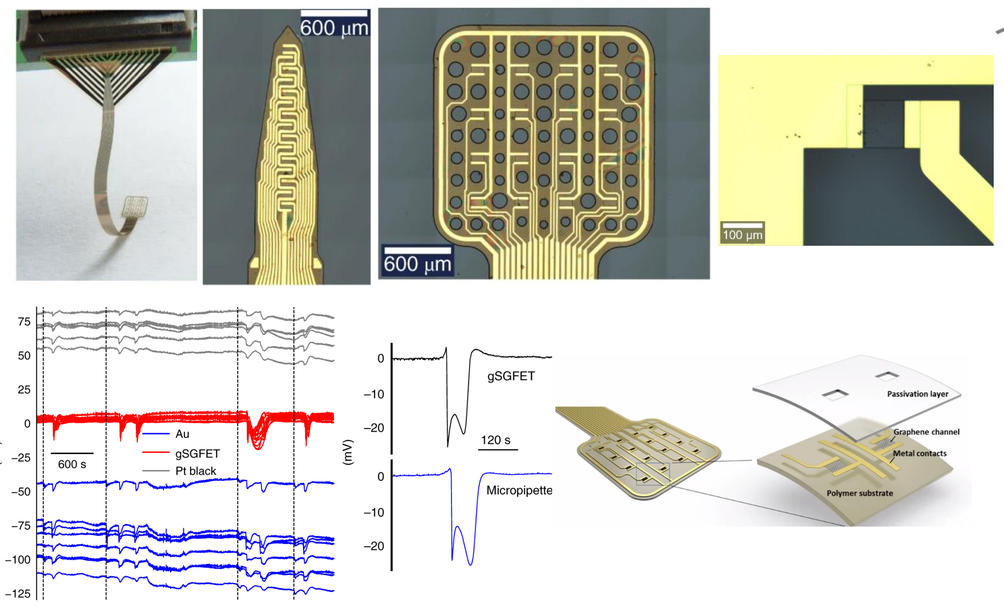
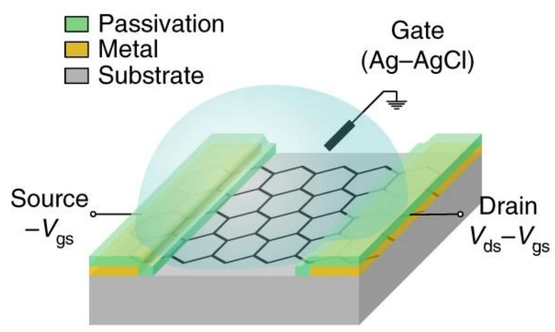
TOWARDS HIGH PERFORMING gSGFETs

High-resolution recording of brain activity

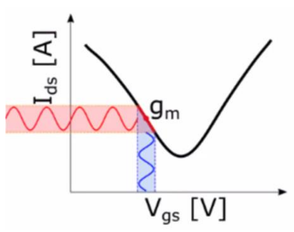


gSGFETs allow the recording of infraslow brain activity (ISA) in a large-scale, implantable, biocompatible clinical system for applications in monitoring and treatment of neurological diseases like epilepsy or stroke [1,2].

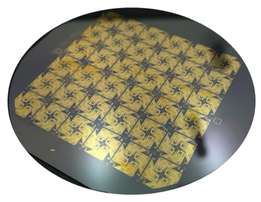
Working principles



Current is modulated by the fluctuations in the surrounding potential of graphene



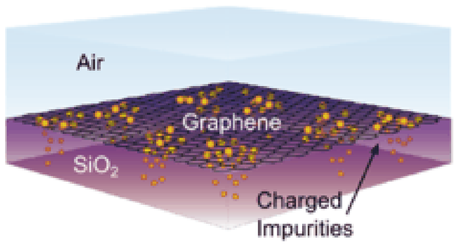
- ✓ High sensitivity
- ✓ Low noise



Challenges

Potential not fully used!

- x Microfabrication contamination
- x Graphene transfer residues
- x Substrate interaction [3]

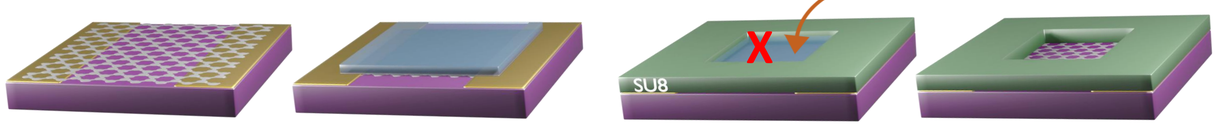


- x **Limited electrical performance**

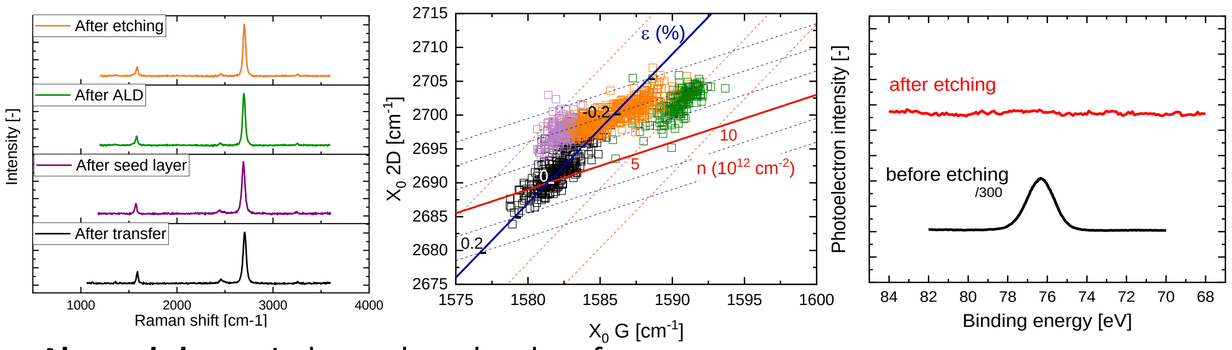
Channel protection with sacrificial layers

Towards **enhanced performance** and **protection against fabrication residues** of gSGFETs a fabrication process modification has been proposed:

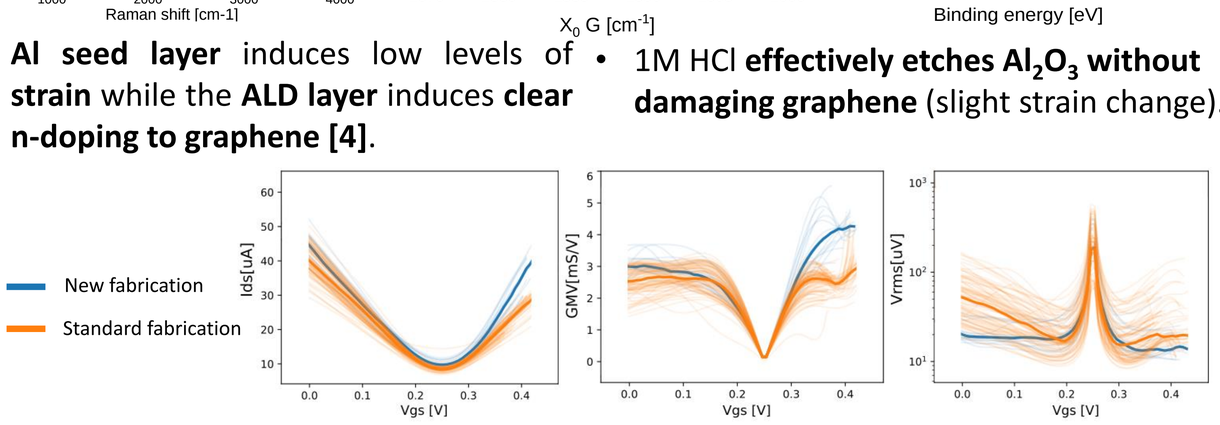
Metal contacts · SU8 passivation · Si/SiO2 · Al+Al2O3



- Low-temperature atomic layer deposition (**ALD**) of **Al_2O_3** with **Al seed layer** approach after graphene transfer.
- **Residue-free** removal of the layer at the end of the fabrication process.

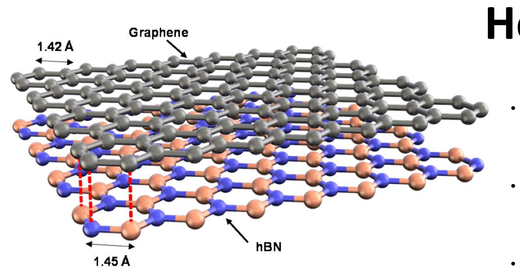


- **Al seed layer** induces low levels of **strain** while the **ALD layer** induces **clear n-doping to graphene [4]**.
- 1M HCl **effectively etches Al_2O_3 without damaging graphene** (slight strain change).



Al_2O_3 protection demonstrates a potential in improving the electrical performance of gSGFETs and future work will focus on optimizing the fabrication process to confirm it.

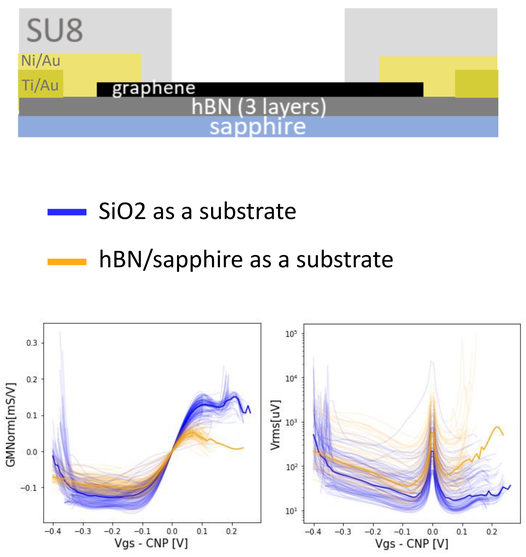
Reducing charge scattering from the substrate



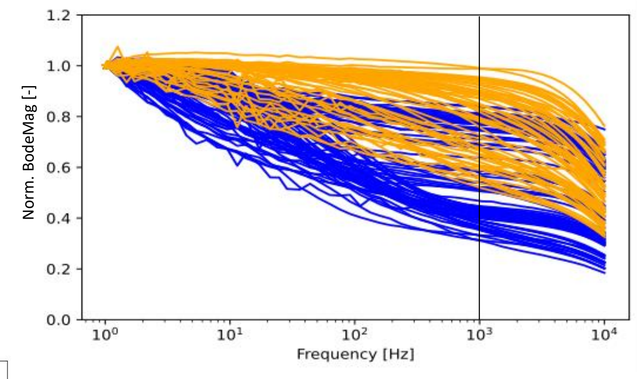
Hexagonal boron nitride (h-BN)

- Reduces substrate interaction
- Reduces charge carrier scattering
- Improves thermal management

- Atomically flat surface (hBN-graphene lattice mismatch: ~1.6%)
- Crystalline structure, wide band gap (5–6 eV)
- High thermal conductivity [4]



1kHz



Keeping constant frequency response up to tens of kHz important for signal recording

Future work will involve exploring the hBN as a decoupling layer on different substrates (SiO2, PI), benchmarking the performance, and understanding its influence on graphene-based devices.

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REFERENCES

1. Masvidal-Codina, E. *et al.* High-resolution mapping of infraslow cortical brain activity enabled by graphene microtransistors. *Nature Mater* 18, 280–288 (2019).
2. Bonaccini Calia, A., *et al.* Full-bandwidth electrophysiology of seizures and epileptiform activity enabled by flexible graphene microtransistor depth neural probes. *Nat. Nanotechnol.* 17, 301–309 (2022)
3. Sule, N., *et al.* EMC/FDTD/MD Simulation of Carrier Transport and Electrodynamics in Two-Dimensional Electron Systems. *Journal of Computational Electronics* 12, no. 4, 563–71 (2013).
4. Lee, J. E., *et al.* Optical separation of mechanical strain from charge doping in graphene. *Nat Commun* **3**, 1024 (2012).
5. Ma, K.Y., Minsu, K. *et al.* Large-Area Hexagonal Boron Nitride Layers by Chemical Vapor Deposition: Growth and Applications for Substrates, Encapsulation, and Membranes. *Accounts of Materials Research* **2022** *3* (7), 748-760