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

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Excellent conductivity, high aspect ratio and single-atom thickness of graphene offer the potential for its miniaturization and integration into fast, sensitive and flexible biomedical devices, particularly for sensing applications such as recording wide-band brain activity [1]. However, wafer-scale integration of graphene into practical devices faces significant challenges related to the manufacturing process, as evidenced by the measured carrier mobility typically being well below its theoretical values [2]. Every photolithography fabrication step can leave behind photoresist contamination, increasing the likelihood of introducing undesired doping, especially in highly reactive grain boundary regions. Furthermore, interaction with the substrate, such as SiO_2 or polyimide (PI), is known to introduce surface charges resulting in the deterioration of the electrical performance of graphene devices [3]. With the aim to mitigate these issues and, therefore, boost charge carrier mobility and improve the frequency response of graphene solution-gated field-effect transistors (gSGFET), we have explored novel approaches for the fabrication process, including a sacrificial top layer protection strategy and a bottom encapsulation of graphene with hexagonal boron nitride (hBN).
The sacrificial protection layer strategy is based on a thin layer of aluminium oxide (Al_2O_3) deposited by low-temperature Atomic Layer Deposition (ALD). This layer is kept during the complete fabrication to protect the graphene channel from contaminants, and is then removed at the end of the process. Impact of the deposited layer and its removal on graphene quality is evaluated with Raman spectroscopy and Atomic Force Microscopy (AFM). Bottom encapsulation of graphene with hBN is used as a way to effectively isolate the graphene from the substrate-induced perturbations, thanks to its atomic thickness, almost identical crystal structure to graphene and high thermal conductivity [4].
gSGFET arrays prepared using the above-described fabrication strategy have been electrically characterized and benchmarked against those fabricated with a standard process [5]. Technology improvements reported here aim to contribute to the development of more sensitive and efficient neural recording devices capable of monitoring brain activity in a wider frequency range.

References

[1] E. Masvidal-Codina et al., *Nature Materials,* 18 (2019) 280–288
[2] B. Chen et al., *Nanoscale,* 6 (24) (2014) 15255-61
[3] JH. Chen, C. Jang, S. Xiao *et al., Nature Nanotechnology,* 3 (2008) 206–209
[4] KY. Ma, et al., *Accounts of Materials Research*, 3 (7) (2022) 748-760
[5] N. Schaefer et al., Carbon, 161 (2020) 647-655

Acknowledgements:
A. Graf acknowledges the support of a fellowship from ¨La Caixa Foundation¨ (ID 100010434). The fellowship code is ¨LCF/BQ/DI22/11940031¨