Flexible Electrolyte-Gated Graphene FET Arrays Towards Implantable Neurochemical Sensing

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Neural interfaces capable of real-time monitoring of neurochemical activity are crucial for advancing our understanding of the brain and its disorders. Graphene's exceptional properties make it an ideal material for these interfaces. Its ability to be functionalized with biomolecules further enables highly specific and sensitive biosensing. Electrolyte-gated graphene field-effect transistors (EG-gFETs) have shown exceptional versatility in biosensing applications, achieving record-low detection limits for biomolecules such as neurotransmitters, DNA, and proteins [1]. Traditionally, these devices are fabricated on rigid substrates such as oxidized silicon wafers, which limits their applicability in flexible or wearable systems. In this work, we present a microfabrication process for ex vivo and in vivo EG-gFETs array with receded gate on a polyimide (PI) substrate (Fig. 1a).

PI substrates offer mechanical flexibility, chemical stability, and compatibility with standard microfabrication processes, while being biocompatible and minimizing mechanical mismatch with neural tissue [2]. Our PI device was fabricated by spin coating an Si wafer and releasing it in the final step (Fig. 1b). We analyzed the electrical and mechanical performance of these devices (Fig. 1c), demonstrating well-defined transfer curves comparable to those on rigid substrates, with transconductances up to 100 µS and stable operation even under bending deformations of around 2 cm bending radius. The temporal stability and signal drift [3] of the EG-gFETs was analyzed under various measurement conditions and compared to rigid devices (Fig. 1d). It was shown that an adequate choice of gate voltage windows is paramount to achieving stable signal and avoid drift behavior (Fig. 1e). The stable behavior allows for future integration of aptamers in the graphene channel for real-time monitoring of chemical activity.

Furthermore, PI's semitransparency enables the use of optogenetic brain stimulation by avoiding total blockage of light. In parallel, we have also developed an optogenetic stimulation probe incorporating a very efficient flip-chip µLED (89µm*150µm*80µm) mounted by a simple pick-and-place process on a 15µm-thin silicon shank [4].

The final probe is capable of outputting over 2.5 mW of power with a wall-pug efficiency up to 14%. In vitro tests demonstrated its stability when submerged in an electrolyte, and in vivo tests proved its viability to evoke brain activity.

A future incorporation of the optogenetic capabilities of the µLED silicon probe with the EG-gFETs biorecognition of biomolecules paves the way toward implantable neural interfaces for the detection and study of neurotransmitters dynamics during in vitro, ex vivo, and in vivo recordings [5].

References

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Figures

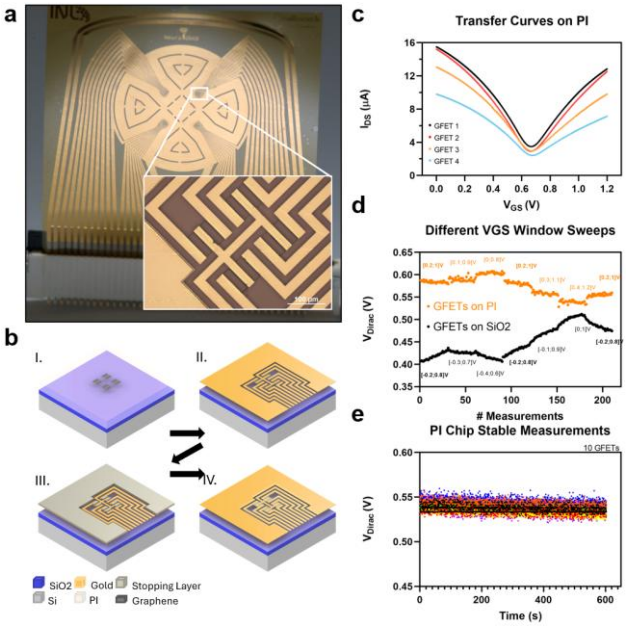

Figure 1. Fabrication and electrical behavior of ex vivo EG-gFETs. (a) Optical image of an ex vivo flexible EG-gFET. (Inset) Optical microscope image of a group of 8 transistors. (b) PI spin coat, graphene transfer, and patterning (I), gold tracks patterning (II), stopping layer deposition (III), and PI passivation spin coat and via opening. (c) Transfer curves of 4 transistors. (d) Comparison between the behavior of rigid and flexible EG-gFETs for different gate voltage windows. (e) Stability of the Dirac voltage for PI chips after optimization of the measurement protocol.