Electronic Supplementary Information

Highly sensitive urine glucose detection by graphene field-effect transistors functionalized with electropolymerized nanofilms

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Characterization of the gFETs

SEM characterization

The gFETs surface was characterized by SEM measurements. **Figure S1** shows the presence of rGO flakes on the glass area of the interdigitated electrodes, thus forming the conducting channel of the transistors.

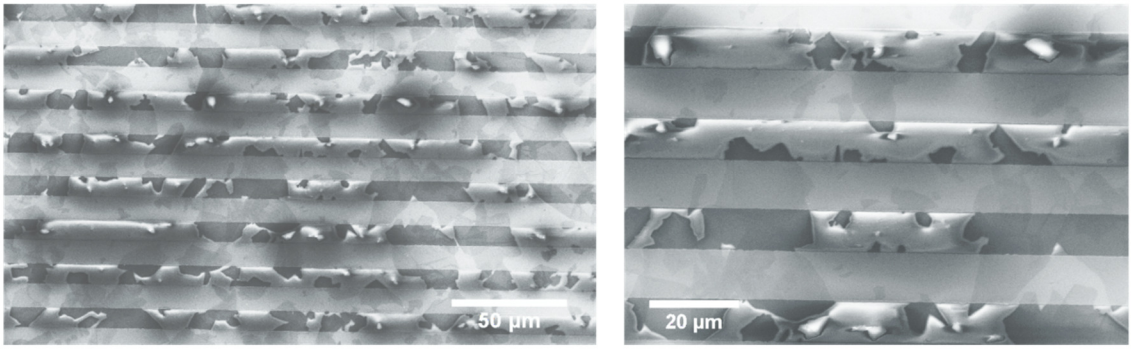

Figure S1. SEM images of the channel area of a bare gFET with different magnifications.

Reproducibility of the fabrication protocol

The reproducibility of the preparation protocol employed was evaluated by recording the resistance between both source and drain electrodes for a batch of 30 gFETs. The results are shown in a box plot in **Figure S2**.

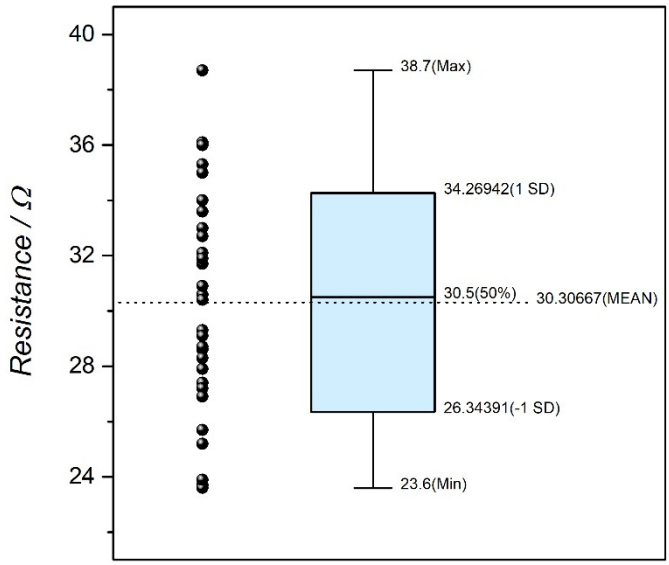

Figure S2. Box plot for the resistance values of 30 gFETs fabricated in the same batch.

Transconductance of the gFETs

In order to evaluate the transconductance of the devices, the first derivative of the transfer characteristics curves of the bare gFETs was calculated.

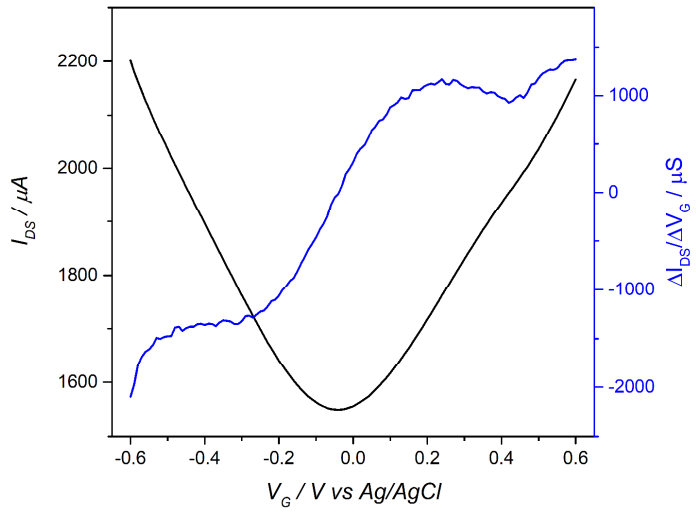

Figure S3. Transfer characteristics and transconductance for a bare gFET (V_{DS} = 0.1 V, KCl 10 mM, HEPES 0.1 mM, pH 7).

Stability of the gFETs upon electropolymerization

In order to study the stability of the gFETs towards the polymerization procedure, the cycling of the gFETs in the highly acidic medium was performed in the absence of the electroactive monomers. The transistors performance recorded in KCl 10 mM, HEPES 0.1 mM, pH 7 showed no changes after 20 voltammetric cycles, as shown in **Figure S4**.

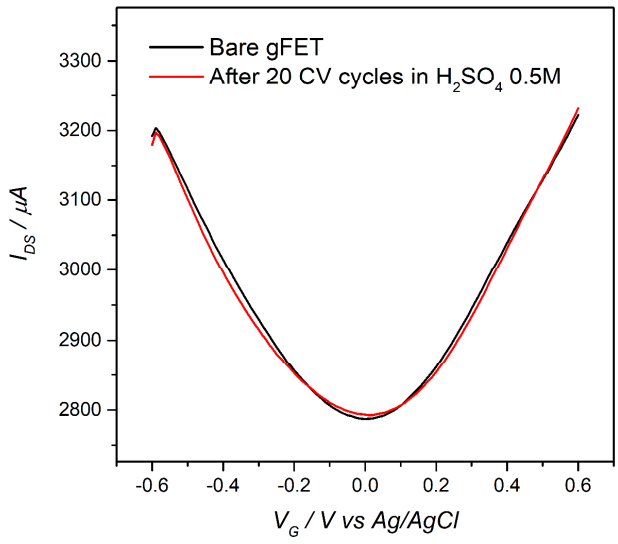

Figure S4. Transfer characteristics and for a gFET before and after 20 voltammetric cycles in H_2SO_4 0.5 M (V_{DS} = 0.1 V, KCl 10 mM, HEPES 0.1 mM, pH 7).

SPR substrates characterization

SEM images were obtained in order to characterize the surface of the rGO-modified Au substrates employed for the SPR measurements. It can be observed that rGO deposition and distribution on the Au surface is similar to that obtained on the IDEs of the gFETs.

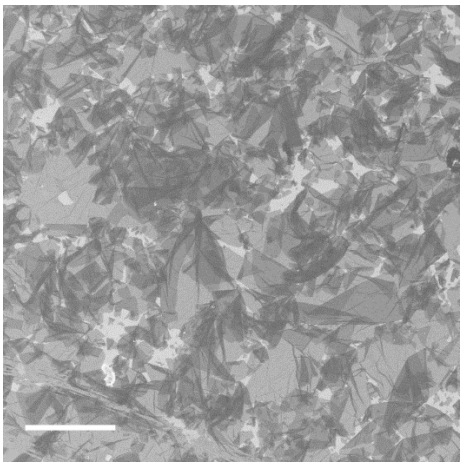

Figure S5. SEM image of an rGO-Au substrate (the scale bar corresponds to 40 µm).

PABA-gFET control experiment

In order to evaluate the effect of glucose addition on the response of a PABA-gFET, the transfer characteristics of a PABA-modified transistor were measured in the absence and presence of 50 µM glucose. No significant change in the Dirac point of the transistor was observed (**Figure S6**).

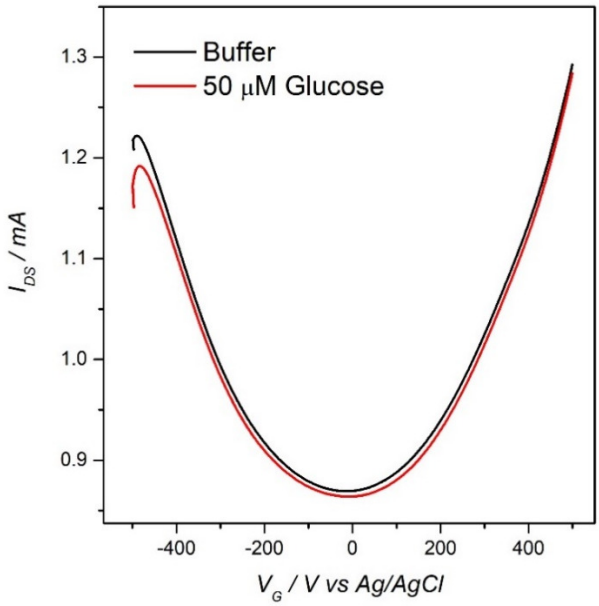

Figure S6. Transfer characteristics of a PABA-gFET in the absence and presence of 50 µM glucose (KCl 10 mM, HEPES 0.1 mM, pH 6, V_{DS} = 0.1V).

Evaluation of H_2O_2 addition

With the aim of evaluating the effect of H_2O_2 addition on the GOx-PABA-gFETs, the transfer characteristics of a biosensor were recorded in buffer in the absence and presence of 50 µM H_2O_2 (**Figure S7**). No significant change is observed in the Dirac point of the transistors upon the addition of H_2O_2. Moreover, this effect was also studied in a flow configuration, showing similar results (**Figure S8**).

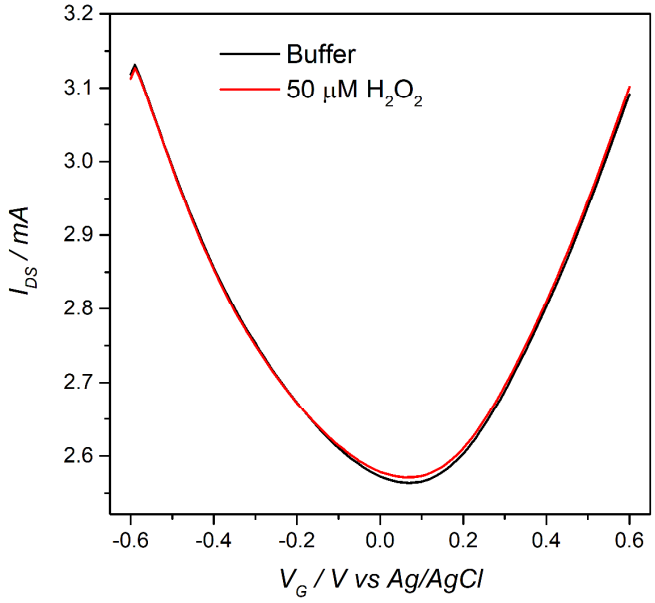

Figure S7. Transfer characteristics of a GOx-PABA-gFET upon addition of H_2O_2 (KCl 10 mM, HEPES 0.1 mM, pH 6, V_{DS} = 0.1V).

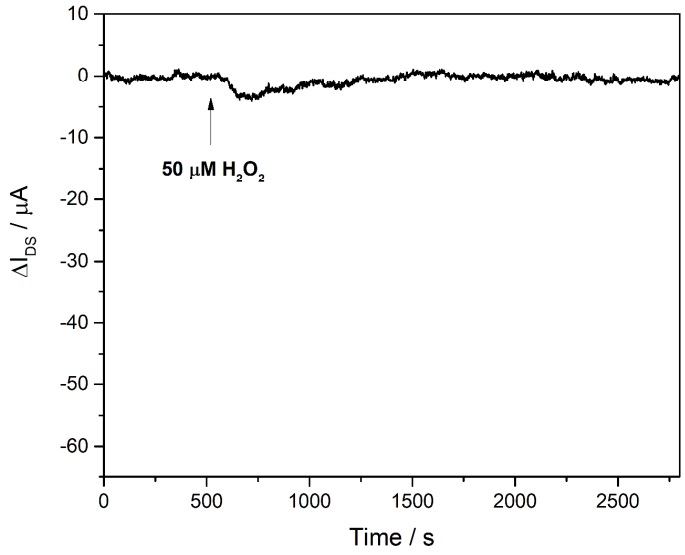

Figure S8. Response of a GOx-PABA-gFET to the flow of H_2O_2 (KCl 10 mM, HEPES 0.1 mM, pH 6, 300 µL/min, V_G = -0.2V, V_{DS} = 0.1V).

Reproducibilty of the biosensors

The data for the reproducibility evaluation of the flow glucose sensing by the developed biosensors is shown in **Figure S9**.

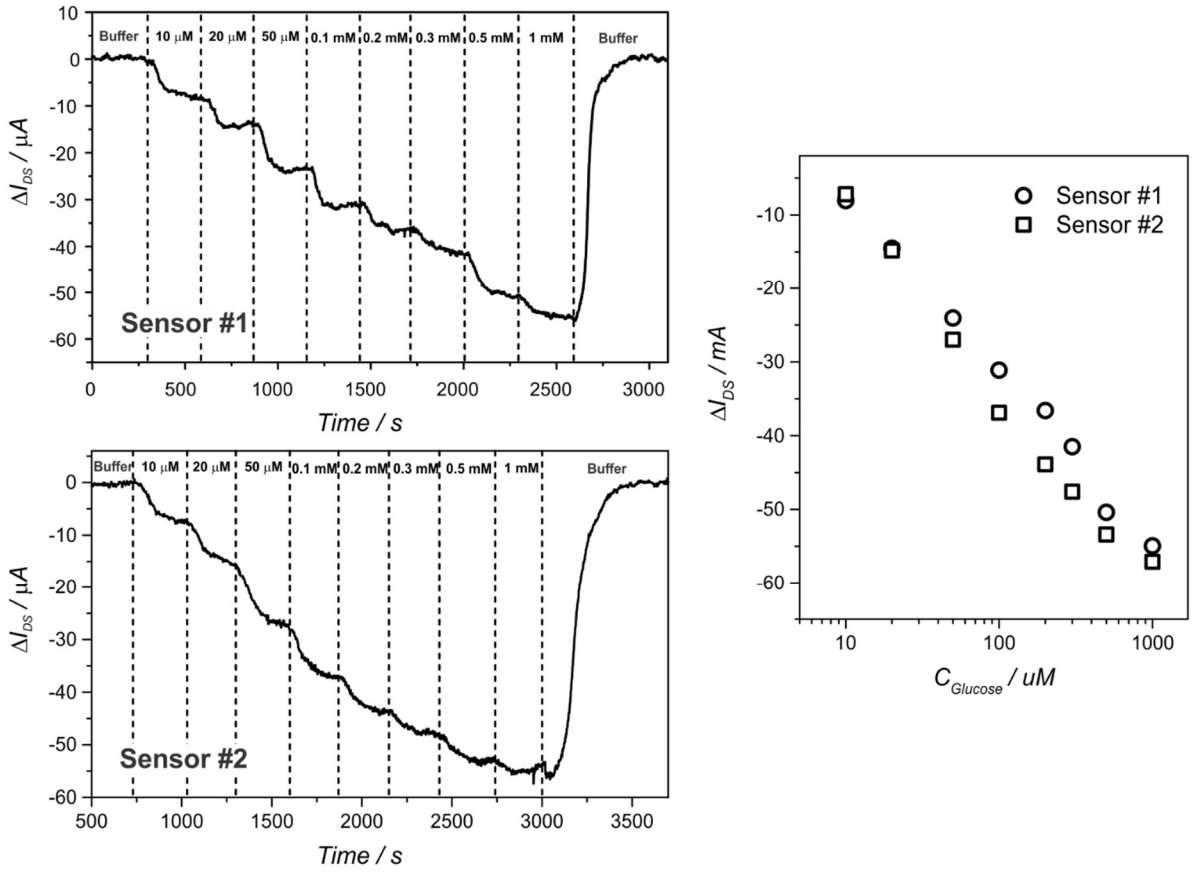

Figure S9. Flow-response of two different GOx-PABA-gFET sensors (300 µL/min, V_G = -0.2V, V_{DS} = 0.1V) for different glucose concentrations (left) and recorded change in I_{DS} (right).

Stability of the biosensors

In order to evaluate the stability of the biosensors, the transfer characteristics of the GOx-PABA-gFETs to the presence of glucose 50 µM were measured after 3 days of storage in buffer at 4°C . The transistors preserved 92% of the original response (**Figure S10**).

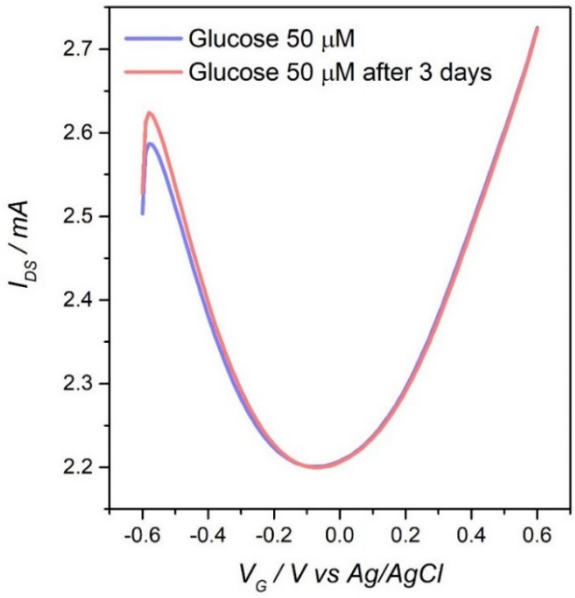

Figure S10. Transfer characteristics of a GOx-PABA-gFET in the presence of 50 µM glucose after 3 days of storage (V_{DS} = 0.1 V, 10 mM KCl, 0.1 mM HEPES, pH 6).

Sensing of glucose in diluted urine

Figure S11 shows the raw data for the determination of glucose in diluted urine. It is observed that the transistors could be used for the glucose determination in diluted urine samples with a very simple signal processing software, without complex baseline subtraction

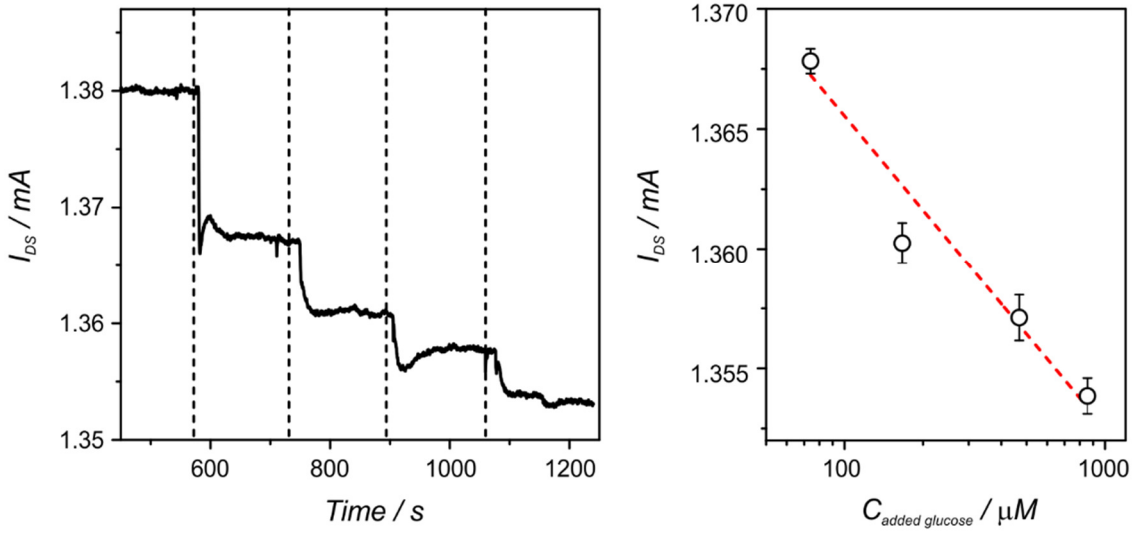

Figure S11. Registered drain-source current for a GOx-PABA-gFET upon the injection of spiked urine samples (V_G = -0.2V, V_{DS} = 0.1V) (left) and linear fitting of the response (results for two measurements) (right).

Comparison with previously reported glucose sensors

To compare the analytical performance of the biosensors developed in this work with that of previously reported sensors in different biological samples, the main features of different devices are presented in **Table S1**. It can be noted that the present biosensors show relatively low LOD, wide dynamic range and low RSD for the determination of glucose in the biological sample.

Table S1. Comparison between previously reported sensors for glucose sensing in different biological samples and the biosensor developed in this work.

Sensor/Method	LOD	Dynamic Range	Biological sample	[Glucose] measured	RSD	Reference
rGO FET with rGO/Au gate	4 µM	0.01-0.4 mM / 0.4-31 mM	Artificial sweat	50, 250 µM	15.4%, 8.9%	[1]
PPy-CNT-Graphene FET	1 nM	1 nM - 0.1 mM	Human, bovine and horse serum	50, 10 mM	3%	[2]
In_2O_3 nanoribbon FET	10 nM	10 nM - 1 mM	Saliva, artificial sweat, and tears	0.1 µM - 1 mM	Not reported	[3]
ZnO-Fe_2O_3 FET	12 µM	0.05 - 18 mM	Mouse blood and serum	4 mM	Not reported	[4]
Si-based ISEFET/ ENFET	0.3 mM	2 mM - 16 mM	Serum	2 - 10 mM	2%	[5]
ZnO NRs FET	0.07 mM	0.07 mM - 80 mM	Serum	5 mM	Not reported	[6]
PEDOT:PSS FET	0.1 mM	0.1 mM – 1 mM	Artificial sweat	0.1 – 1 mM	Not reported	[7]
PABA-rGO FET	4 µM	10 µM - 1 mM	Urine	40 – 900 µM	5%	**This work**

Comparison with a commercial sensor

To compare the biosensors developed in this work with a widely employed commercial sensor for urine determination (glucose strips, Medi-Test ®), the main features of both devices are presented in **Table S2** (data from the manufacturer, https://www.mn-net.com/de/harnteststaebchen-medi-test-glucose-93024). The biosensors developed show several advantages such as low response to interferences, lower essay time and quantitative determination of the analyte, among others.

Table S2. Comparison between a commercial urine glucose sensor and the biosensor developed in this work.

	Medi-Test® glucose strips	This work
LOD/LOQ	1.1 mM	4.1 µM / 14 µM
Specificity/Interferences		
• Ascorbic Acid	Yes, in some cases	No
• Peroxide	Yes	No
• Other interferents	Phtalein, gentisic acid	Was not studied
Linear range	1.1 mM – 55.5 mM	14 µM – 1 mM
Determination	Semi-quantitative	Quantitative
Essay time	30 – 60 seconds	30 – 40 seconds
Time sensitive	Yes (essay time must be < 60 seg)	No
Reusability	No	Yes

References

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