Supplementary Notes

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Mask design

In the Mo/graphene mask, holes are designed to promote a better adhesion of the metal layer (Al (1%Si) / Ti) that will be applied on top of graphene with the layer underneath (SiO$_x$). In the Al/metal mask, the metal layer on top of the electrode is smaller such that it can easily be removed from graphene when needed. Moreover, once the metal is being removed, the graphene electrode area should not be fully exposed but protected against possible delamination, at its outermost ring, by the polymer on top (smaller opening on in the polymer opening mask for the electrodes). The metal layer on the contact pads of graphene is slightly larger than graphene contact pads. The reason is the adhesion needed to keep the metal layer on top of graphene until the final steps of microfabrication process.

Fig. S1. Masks used for the microfabrication of full implant devices. The electrode diameter is 340 µm which leads to an area of 90792 µm$^2$. However, the total surface area after subtraction of the holes is 68320 µm$^2$. 
Additionally, in the polymer opening mask, the dimensions of the openings for the contact pads are the same as for the graphene pads, to ensure that graphene pads are completely covered by the metal layer. This Al metal layer on the contact pad was also designed for soldering wires to the contact pads. However, the openings for the electrodes are smaller than the metal to avoid damaging the graphene layer in case of misalignment of the mask during the lithography steps.

Graphene, Pt and Au electrodes on Si

Graphene electrodes on Si

![Graphene electrodes on Si](image_url)

Fig. S2. Fabrication process steps for graphene electrodes on Si. (a) 300 nm wet thermal oxide grown on the frontside of a single-sided polished (SSP) Si wafer, (b) Mo deposition and pattern, (c) Graphene growth, (d) 4μm photoresist coating as an insulation layer. The photoresist is finally patterned and etched only on the electrodes and contact pads.

Pt and Au electrodes on Si
Sheet resistance measurement

Van der Pauw structures for four-point probe measurements

Fig. S4. Van der Pauw structures used for measuring the sheet resistance of graphene layers with different growth times (20, 40, and 60 min). Contact pads were covered with a drop of silver (Ag) ink to prevent any damage caused by the measurement probes on the graphene.
Four-point probe measurements were performed with a Cascade Microtech probe station. The four probes were positioned on the Ag ink dots on the extremities of the Van der Pauw structures. The current was forced between Probes 1 and 2 ($I_{1,2}$), by setting the Probe 1 potential from -1 V to 1 V with 8 mV steps and Probe 2 acting as ground. The voltage was measured between Probes 3 and 4 ($V_{3,4}$). The sheet resistance ($R_{sh}$) was calculated using the equation below for each point in $\Omega$/sq unit, which were then averaged, excluding the values around $I = 0$.

$$R_{sh} = \frac{V_{3,4} \pi}{I_{1,2} \ln 2}$$

**Graphene transfer process**

The method used for graphene transfer started with a full wafer with graphene grown on non-patterned Mo. The wafer was then manually diced into roughly 2 cm$^2$ pieces. These were then placed in a beaker where $H_2O_2$ was added just until the height of the Si piece with graphene. Mo then started to etch from the sides towards the centre, as illustrated in Fig. S5 (a). After all the Mo was etched, the graphene was separated from the silicon piece and floated on the surface of the liquid while the silicon fell to the bottom of the beaker. DI water was then added very gently with a pipette until the level of the liquid rose about 2 cm. The floating graphene was then scooped on the glass slide. One drop of Triton X100 was added to 1 litre of DI water and 50 ml of triton-water solution was added to the $H_2O_2$ in the beaker to reduce surface tension. The resulting glass slides with transferred graphene are shown in Fig. S5 (b).
Figure of merit (FOM)

To evaluate the quality of a transparent conductive film (TCF), the figure of merit (FOM) is calculated based on optical transmittance ($T$) at 550 nm wavelength and sheet resistance ($R_{sh}$). Films with low $R_{sh}$ at high optical transmittance show higher performance as a TCF, therefore, a higher FOM corresponds with better TCF performance. The most widely used FOM is defined as follows:

$$FOM = \frac{188.5 \sqrt{T}}{R_{sh}(1 - \sqrt{T})}$$

The FOM calculated based on this equation can be used to evaluate all films with different thicknesses, synthesised from different methods and materials.

The reported values in this work are comparable with the result from graphene electrodes manufactured using a CVD process and also higher than the theoretical value (2.55) calculated by the same equation for an undoped monolayer graphene. However, the calculated FOM is as expected a lot lower than the one of ITO (60 for 40 nm).

Fig. S5. Sample preparation for optical transmittance measurement, (a) graphene transfer process to glass slides, (b) graphene with 20 min growth time transferred to a glass slide
**Photo-induced artifact**

![Diagram of setup](image)

Fig. S6. Setup used for photo-induced artifact test. An Intan RHD2000 Evaluation System was used for data acquisition. A 200 μm diameter fiber was used to shine the light from an LED (M470F1, Thorlabs) on an electrode site. The electrode and the RHD headstage were both put inside a Faraday cage to prevent any interference.

**MRI sequences and parameters**

Table S1. MRI sequences and parameters used to acquire each image

| Sequence          | Acquired images | Acquired resolution (mm³) | Field of view (FOV) (mm²) | Nr. slices | Nr. echos | T_R (Repetition time) (ms) | T_E (Echo time) (ms) | Flip angle (°) | Sense |
|-------------------|-----------------|---------------------------|----------------------------|------------|-----------|---------------------------|--------------------|---------------|-------|
| Dual-echo GRE     | T2*-weighted    | 0.7×0.7×0.7               | 150×131                    | 70         | 2         | 22                        | T_E1 = 6.2, T_E2 = 15.2 | 15            | -     |
| SSh GRE EPI       | T2*-weighted    | 1.4×1.4×1                 | 150×150                    | 30         | 1         | 3681                      | 50                 | 90            | -     |
| Multi-echo GRE    | T2*-weighted, T2* maps | 1.8×1.8×2              | 200×200                    | 10         | 15        | 19                        | T_E1 = 1.96, ΔT_E = 1.1 | 25 Factor = 2 |       |
| Spoiled GRE       | T2*-weighted, B0 maps | 0.2×0.2×7               | 110×28                     | 1          | 2         | 2400                      | T_E1 = 15, T_E2 = 25   | 70            | -     |

**Electrical impedance spectroscopy (EIS)**

The EIS data for graphene electrodes using 40- and 60-min graphene growth recipes are shown in the Fig. S6 (a, b), respectively. The impedance of three 40-min graphene electrodes at 1kHz
are 13.1, 47.4, and 56.4 kΩ and the impedance of three 60-min graphene electrodes are 18.2, 23.8, and 47.8 kΩ. Therefore, to be able to draw a conclusion about the influence of graphene number of layers on impedance larger number of samples is required as there are noticeable variations in the impedance for different samples.

Equivalent circuit model

The equation used for \( Z_{\text{CPE}} \) in the equivalent circuit model is:

\[
Z_{\text{CPE}} = \frac{1}{Q(j\omega)^n}
\]

where \( j \) is the unit imaginary number for which it holds that \( j^2 = -1 \), \( \omega \) is the angular frequency being \( 2\pi \) times the frequency of the AC signal \( (\omega = 2\pi f) \), \( Q \) is a measure of the magnitude of
$Z_{CPE}$, and $n$ is a constant in the range between 0 to 1. When $n = 1$, $Z_{CPE}$ is a purely capacitive impedance element, and $Q$ is capacitance; when $n = 0$, $Z_{CPE}$ is a purely resistive element, and $Q$ is its conductance, the reciprocal of its resistance. For practical electrode–electrolyte interfaces, the $Z_{CPE}$ is used instead of a pure capacitance, accounting for the non-ideal capacitive behavior of the electrochemical double layer.

The equation used for $Z_{WB}$ in the equivalent circuit model is:

$$Z_{WB} = \frac{W_B}{\sqrt{j\omega}} \times \tanh(\frac{\sqrt{j\omega}}{B})$$

Where $W_B$ is the finite-length Warburg coefficient and $B$ is:

$$B = \frac{\sqrt{D}}{\delta}$$

Where $D$ is the diffusion coefficient and $\delta$ is the thickness of the diffusion layer.

**Cyclic voltammetry (CV)**

The CV scan started at 0 V, then the potential increased until the upper limit. Next, the potential decreased to the lower limit and after that returned back to 0 V. The scan was repeated 3 times to stabilise the signal, and the third scan was used in the calculation of the CSC. The CSC is calculated based on the time integral of the CV curve. The calculated charge was then divided by the electrode surface area (68320μm$^2$) to obtain the charge density. Finally, the CSC was expressed in μC/cm$^2$.

**Atomic force microscopy (AFM)**
Since any surface roughness greatly increases the CSC due to an increase in the electrochemical surface area of the electrode, the prepared graphene samples were characterized by atomic force microscopy (AFM). AFM was conducted using an NTEGRA Spectra system at ambient conditions. The morphology was captured in the tapping mode with a NSG01 probe. The surface roughness was measured across the $50 \times 50 \, \mu m^2$ areas, calculated as the root-mean square of the height distributions, and then averaged. The phase lag of the AFM probes was measured simultaneously with the topography to achieve better contrast of small topographic features. High-quality images were processed in the standard way using Gwyddion, applying polynomial correction of the background. Then, surface characterization was used to determine the surface roughness.

**EDX measurement**

For this measurement, Mo is deposited on a Si wafer with a pre-deposited SiO$_2$ layer. Next, graphene is grown on Mo catalyst. Then, the Mo is etched using a simple wet etching process (using H$_2$O$_2$) as was also used in the paper. To verify that there is no Mo residue energy dispersive X-ray (EDX) (FEI XL30 SFEG, w. EDAX Octane Plus detector) analysis was performed. During the EDX measurement the electrode surface after Mo removal was focused using 15 kV electron beam and a spot size of 6. The elemental mapping results acquired after 92 minutes represented in Fig. S9 show the presence of Si, O, C, and Mo and the corresponding spectrum. The indicated areas with graphene and without graphene in the SEM image matches with the C map.

Details of the atomic and weight percent of each element are listed in the inset Table represented on the right side of the diagram.
At the location where normally the Mo peak is found (2.293eV) no clear feature can be distinguished above the noise floor. Upon manually selecting Mo as element, 0.03 weight and 0.01 atomic percentages are attributed to this element. However, the thin layer of graphene is still present and EDX was able to distinguish it.

Fig. S9. SEM image, EDX elemental mapping, and the map spectrum of the graphene electrode after Mo removal