# Integrated Graphene


## Gii-Sens

An Introductory Comparison of Premium Commercially Available Electrode Performance

## Integrated Graphene

Made from our patented, revolutionary 3D Graphene Foam (3DG), Gii, Gii-Sens is the world's first pure 3DG sensing electrode. Our electrode harnesses the excellent electrochemical properties of graphene to produce unparalleled sensitivity, reliability, purity and conductivity due to a very large electrochemically active area. With Gii-Sens, you can deliver accurate, multiplexed point-of-care diagnostic testing in a much shorter timeframe than conventional laboratory testing. Integrated Graphene can offer a range of bespoke solutions and develop novel, powerful, and cost-effective microfluidic assays. Contact us today if you want to be a part of the new wave of biosensing assays.


## Summary

We have assessed our electrodes against commercially available premium graphene-based, carbon-based and screen-printed gold electrodes. Gii-Sens successfully outperforms, or equals, all of these traditional sensing electrode materials on reduction-oxidation peak current density, reduction-oxidation peak separation and surface charge transfer resistance. The disruptive potential of the Gii-Sens 3DG electrode is clear in its overall unparalleled performance.


## Benchmark Experimental Conditions:

- 1 mM Potassium Ferri/Ferrocyanide in 0.1 M Potassium Chloride and minimum number of five replicates randomly picked.
- Cyclic voltammetry at 25 and 200 mV/s scan rate performed as comparative technique. Various features were investigated and conclusions were drawn to evaluate the different electrode material performances.
- Electrochemical impedance spectroscopy was performed at equilibrium potential with 5 mV amplitude and from 0.1 to 100 kHz frequencies.
- A sensor built-in or external silver/silver chloride reference electrode was used.
- No pre-treatment of the electrode was required.

## Gii-Sens vs. Other Graphene Electrode Materials

Gii-Sens was evaluated and compared against two premium commercially available graphene-based sensors: Company D graphene and Company Z graphene.

## Reduction Oxidation Peak Current Density

To assess the relative electrochemically active surface area of each material, reduction – oxidation peak current density was measured by cyclic voltammetry. As seen in figure 1, the peak current density obtained shows a 25% increase in available electrochemically active area per geometrical area unit in Gii-Sens, compared to Company D Graphene and Company Z Graphene. This is a clear reflection of the larger electrochemically available surface area provided by Gii-Sens 3DG.

Figure 1

Reduction - Oxidation Peak Current Density (25mV/s)

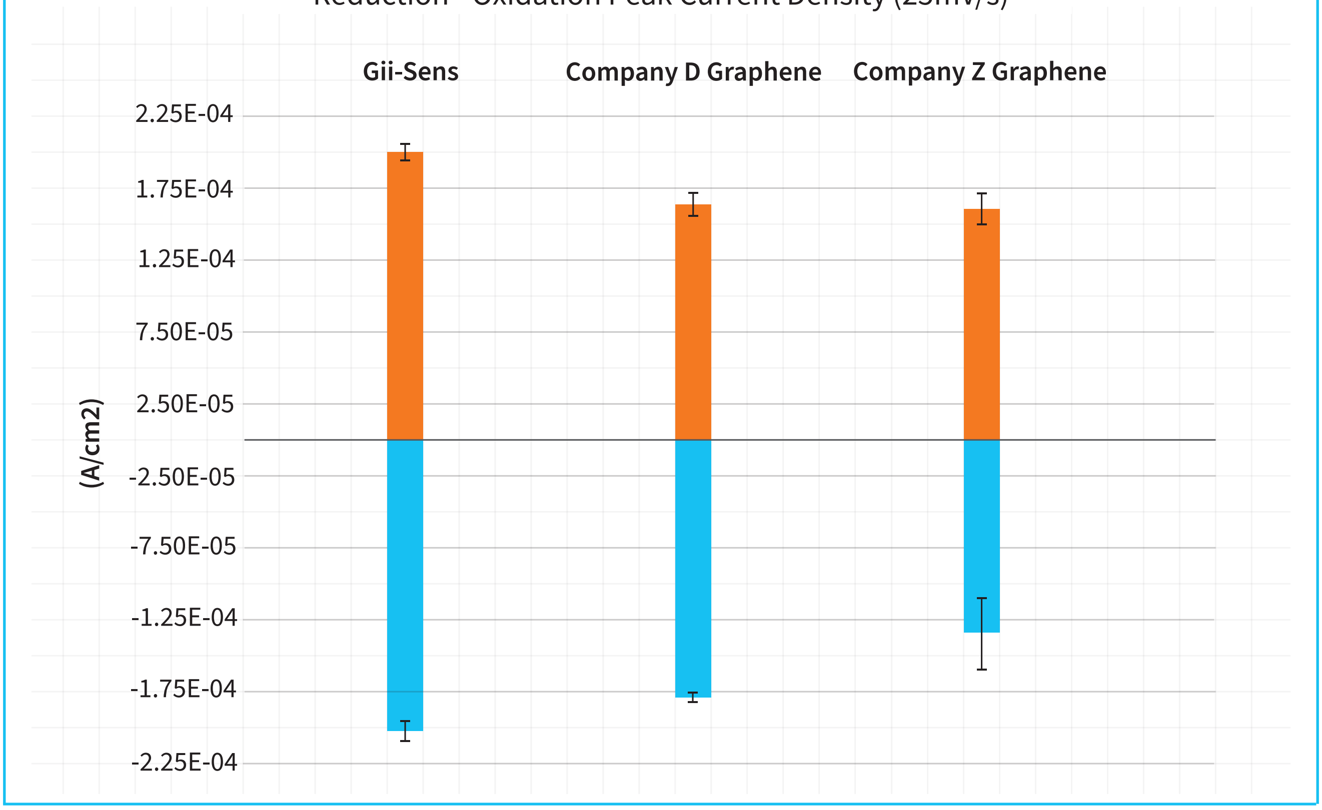


Figure 1: Cyclic voltammetry reduction - oxidation peak current density (25mV/s) for Gii-Sens and two commercially available graphene-based electrodes: Company D Graphene and Company Z Graphene. Gii-Sens shows 25% greater current density per geometrical area than Company D Graphene and Company Z Graphene.

## Reduction Oxidation Peak Separation

Peak separation, when assessed by cyclic voltammetry, can be interpreted as a measure of the electron redox responsiveness of the surface to voltage scan and its ability to effectively perform rapid redox reactions. When compared, again, to Company D Graphene and Company Z Graphene, Gii-Sens offers much lower reduction – oxidation peak separation below 70 mV and shows no increased separation from 25 to 200 mV/s (figure 2). The two other electrodes studied showed larger voltage separation from reduction to oxidation, indicative of less efficient redox faradaic reactions and a clear detrimental effect associated with faster scan rates.

Figure 2

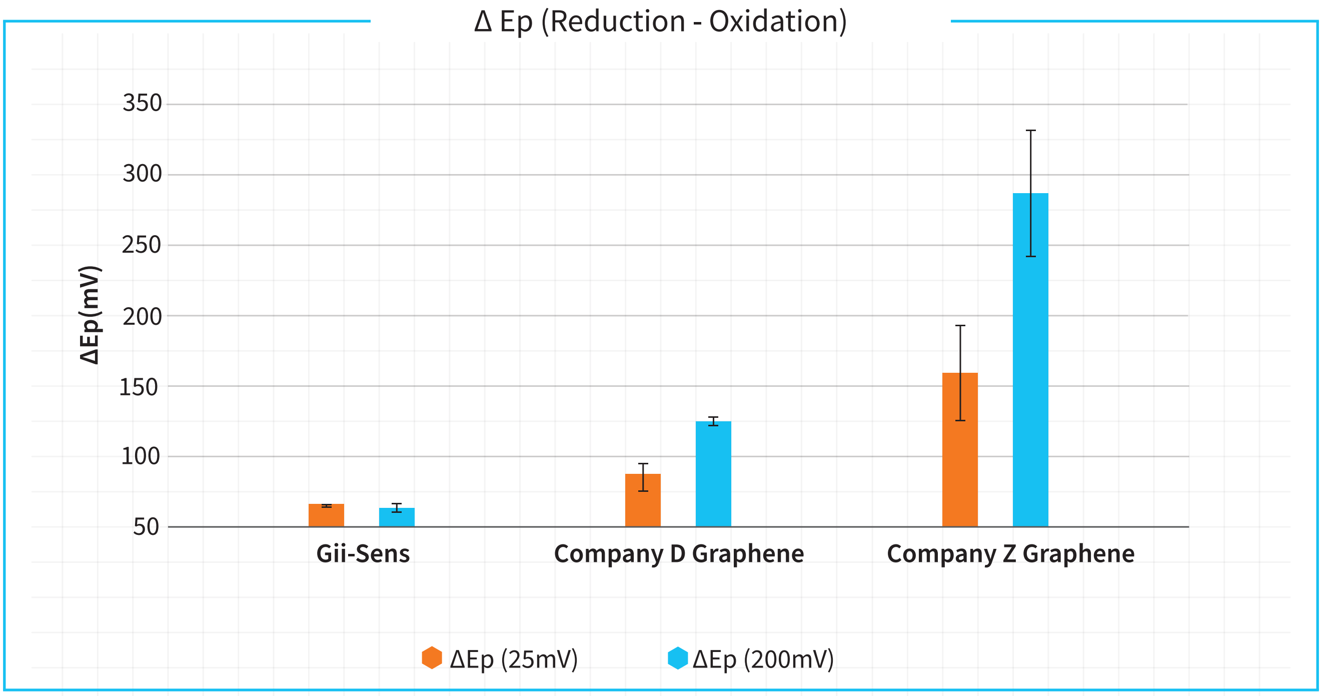


Figure 2: Reduction – oxidation peak separation (ΔEp) at 25mV and 200mV obtained by cyclic voltammetry for Gii-Sens, Company D Graphene and Company Z Graphene. Gii-Sens shows lower peak separation than Company D Graphene and Company Z Graphene at both 25mV and 200mV.

## RCT – Charge Transfer Resistance

Charge transfer resistance (Rct Ω) was measured by electrochemical impedance spectroscopy (EIS) to assess the material resistance when transferring charge from its surface. As depicted in figure 3, the value of charge transfer resistance at the different graphene surfaces shows a dramatic improvement at the Gii-Sens sensor surface. This illustrates the massive potential of Gii-Sens for implementing impedance-based measurements with reliability and little background signal interference.

Figure 3

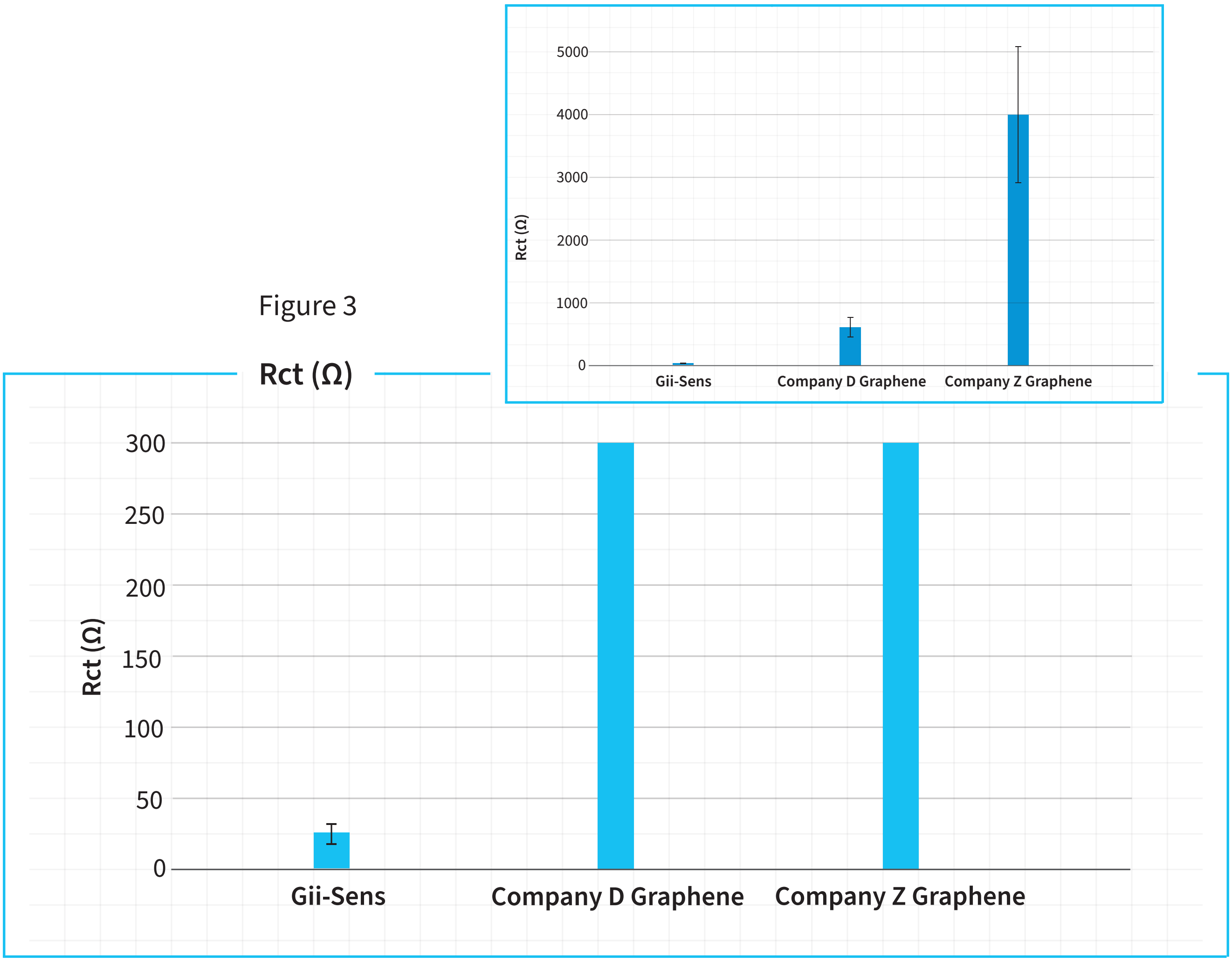


Figure 3: Charge transfer resistance (Rct Ω) of Gii-Sens measured by EIS, Company D Graphene and Company Z Graphene. Gii-Sens has much lower charge transfer resistance at the sensor surface when compared to Company D Graphene and Company Z Graphene.

## Gii-Sens vs. other Premium Carbon-Based Materials

Carbon-based electrode materials are very common in electroanalytical applications and carbon paste is a common material for screen-printed sensors. They are the most widespread electrode surface in real point-of-care applications due to their fabrication flexibility and affordability. On the other end of carbon-based materials, there are glassy carbon surfaces with expected better performance but a limited availability for flexible manufacturing and affordability.

## Reduction Oxidation Current Density

Measurement of reduction – oxidation current density by cyclic voltammetry shows that Gii-Sens matches the performance of pure glassy carbon in terms of available electrochemically active area whilst increasing by 50% the area available at equivalent sized carbon paste electrodes (figure 4).

Figure 4

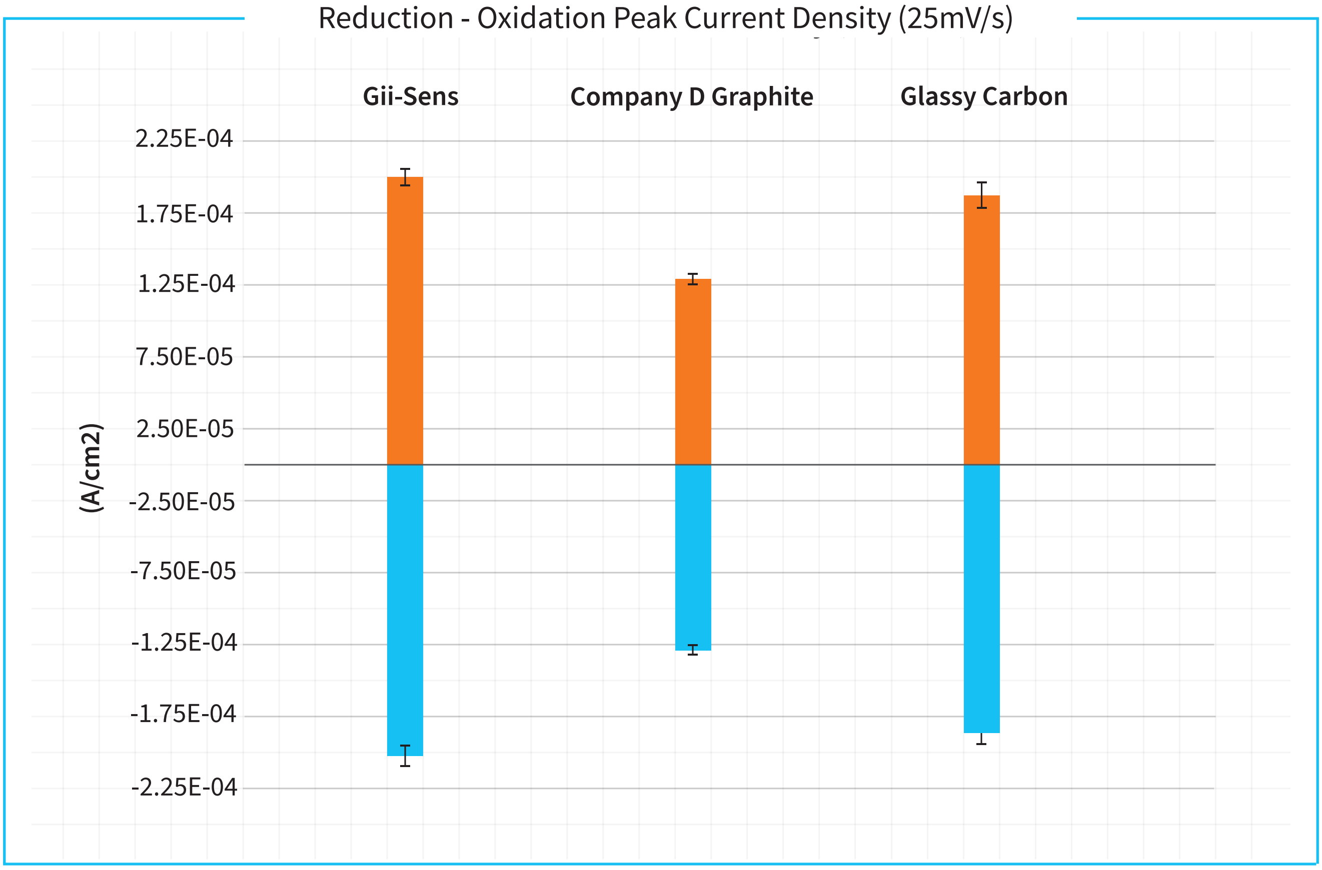


Figure 4: Cyclic voltammetry reduction - oxidation peak current density (25mV/s) for Gii-Sens, Company D Graphite and a glassy carbon electrode. Gii-Sens matches glassy carbon reduction – oxidation current density and has an area available 50% larger than the Company D Graphite electrode.

## Reduction Oxidation Peak Separation

As seen in figure 5, the reduction – oxidation peak separation obtained from cyclic voltammetry shows the relatively poor performance of the carbon paste material and its high dependence on slow scan rates to deliver relatively acceptable redox reactions at its surface. The response of Gii-Sens even outperforms that of pure glassy carbon at any scan rate, showing its great potential in combining manufacturing flexibility and excellent performance.

Figure 5

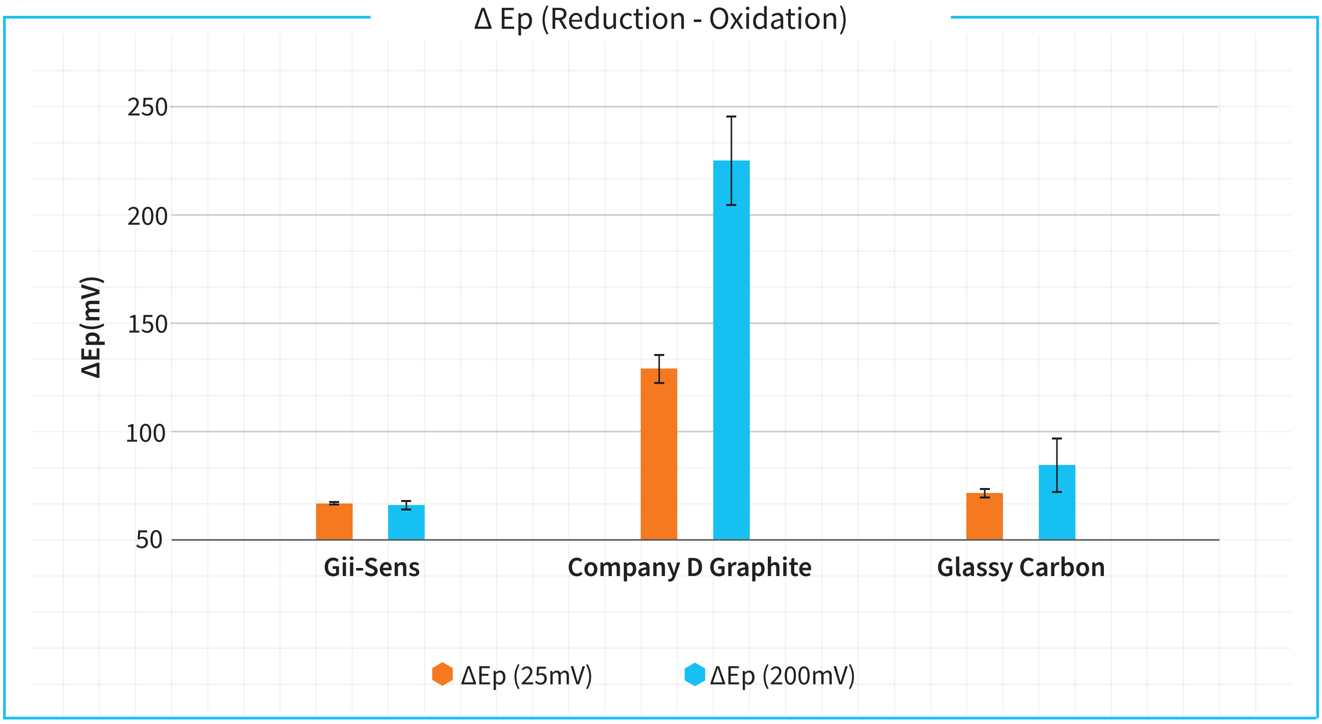


Figure 5: Cyclic voltammetry reduction – oxidation peak separation (ΔEp) at 25mV and 200mV for Gii-Sens, Company D Graphite and a glassy carbon electrode. Gii-Sens outperforms both other electrodes at both scan rates.

## RCT – Charge Transfer Resistance

As shown in figure 6, the Gii-Sens charge transfer resistance, measured by EIS, is much lower than the other two electrodes tested. The measure of surface charge transfer resistance comes to emphasise that Gii-Sens holds tremendous potential as an impedance-based sensing surface superior to glassy carbon and opening a field still unreachable for carbon paste electrode materials.

Figure 6

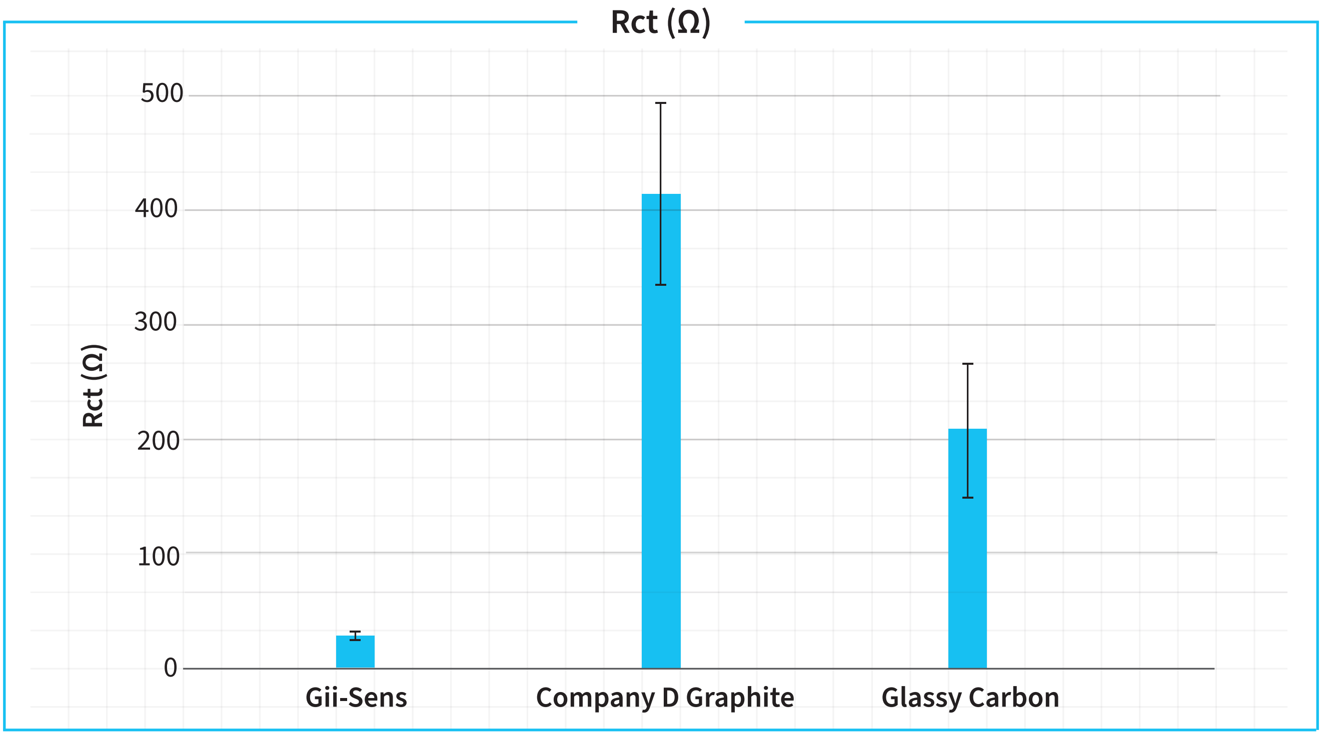


Figure 6: Charge transfer resistance (Rct Ω) of Gii-Sens, Company D Graphite and a glassy carbon electrode. Gii-Sens shows a much lower Rct than the other two electrodes tested.

## Gii-Sens vs. Screen-Printed Gold

Screen-printed gold sensors are hosts of two of the most important properties required to make a sensor material feasible for real electrochemistry sensing applications: excellent electrochemical responsiveness and flexible fabrication procedures, requiring little infrastructure for manufacturing and adaptable to many applications. Gii-Sens graphene proves to also host these properties, with the additional benefit of affordability. Two commercially available examples of screen-printed gold were evaluated against Gii-Sens.

## Reduction Oxidation Current Density

Reduction – oxidation current density, measured by cyclic voltammetry, was carried out on Gii-Sens and two commercially available screen-printed gold electrodes: Au-BT and Au-AT. As shown in figure 7, the reduction and oxidation peak current recorded shows at least a 20% increase in available electrochemically active area per geometrical area unit in Gii-Sens when compared to Au-BT and Au-AT.

Figure 7

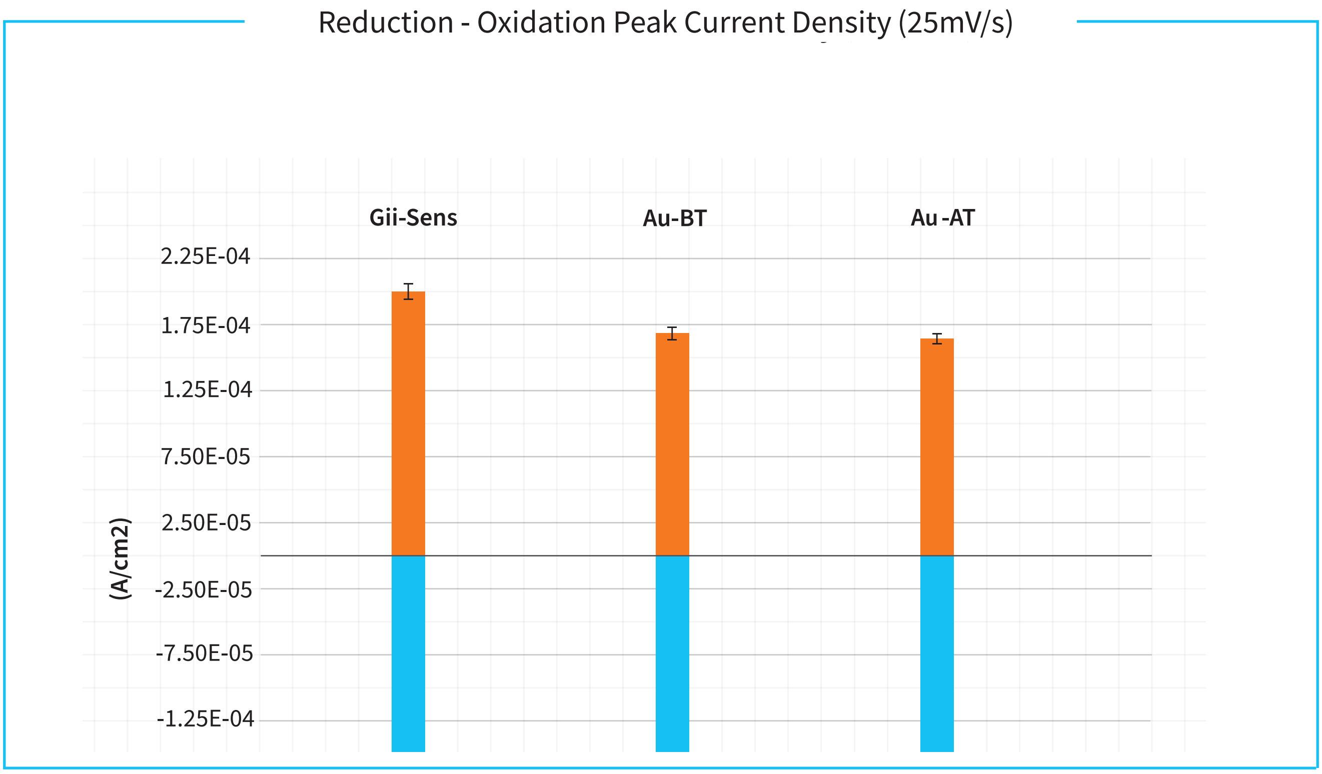


Figure 7: Reduction - oxidation peak current density (25mV/s) obtained from cyclic voltammetry experimentation for Gii-Sens and two commercially available screen-printed gold electrodes: Au-BT and Au-AT. Gii-Sens has a 20% larger electrochemically active area than Au-BT and Au-AT.

The reduction – oxidation peak separation measured by cyclic voltammetry for Gii-Sens, Au-BT and Au-AT is shown in figure 8. As expected, screen-printed gold shows the most responsive electrode surface material of those evaluated. However, Gii-Sens matches and even improves that performance, especially at fast scan rates.

Figure 8

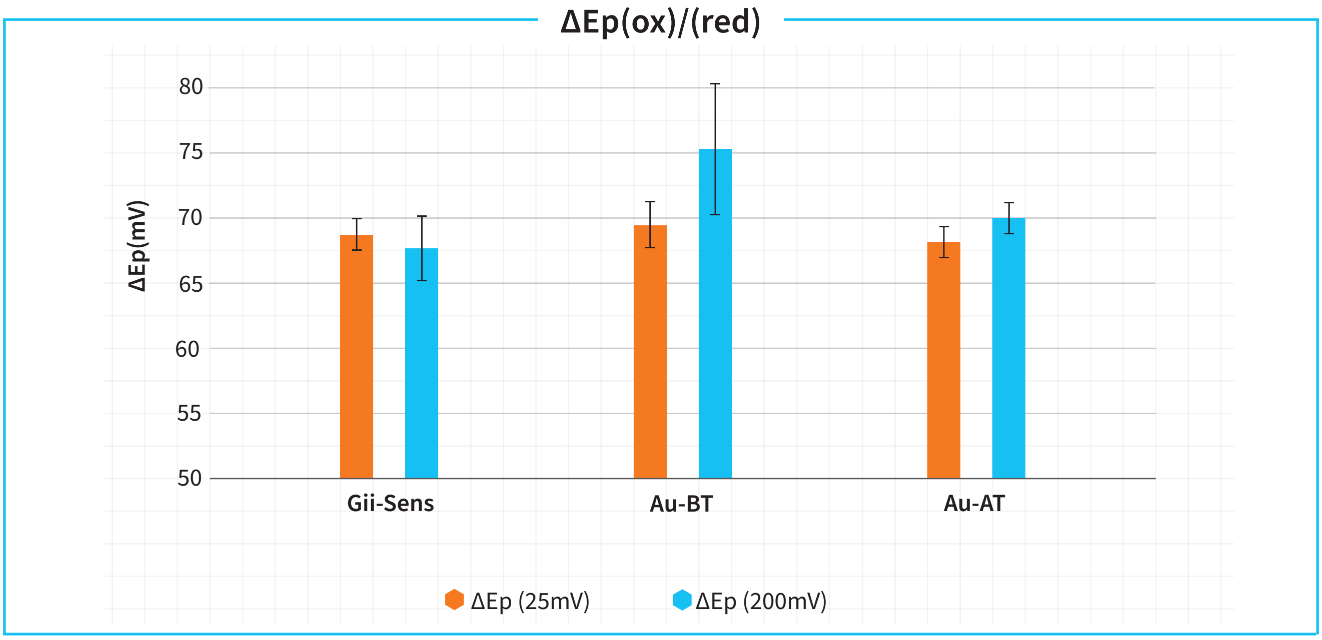


Figure 8: Cyclic voltammetry reduction – oxidation peak separation (ΔEp) at 25mV and 200mV for Gii-Sens, Au-BT and Au-AT. Screen-printed gold shows the most responsive surface, but Gii-Sens performance is superior at fast scan rates.

## RCT – Charge Transfer Resistance

Finally, charge transfer resistance in Gii-Sens and screen-printed gold electrodes was measured by EIS. As shown in figure 9, Gii-Sens shows lower resistance charge transfer than the two screen-printed gold electrodes Au-BT and Au-AT. This evaluation of Gii-Sens against screen-printed gold aims to show the winning comparison in terms of ease of manufacturing and outstanding performance, whereas the affordability and scalability are definitively beneficial inherent features of Gii Sens sensors.

Figure 9

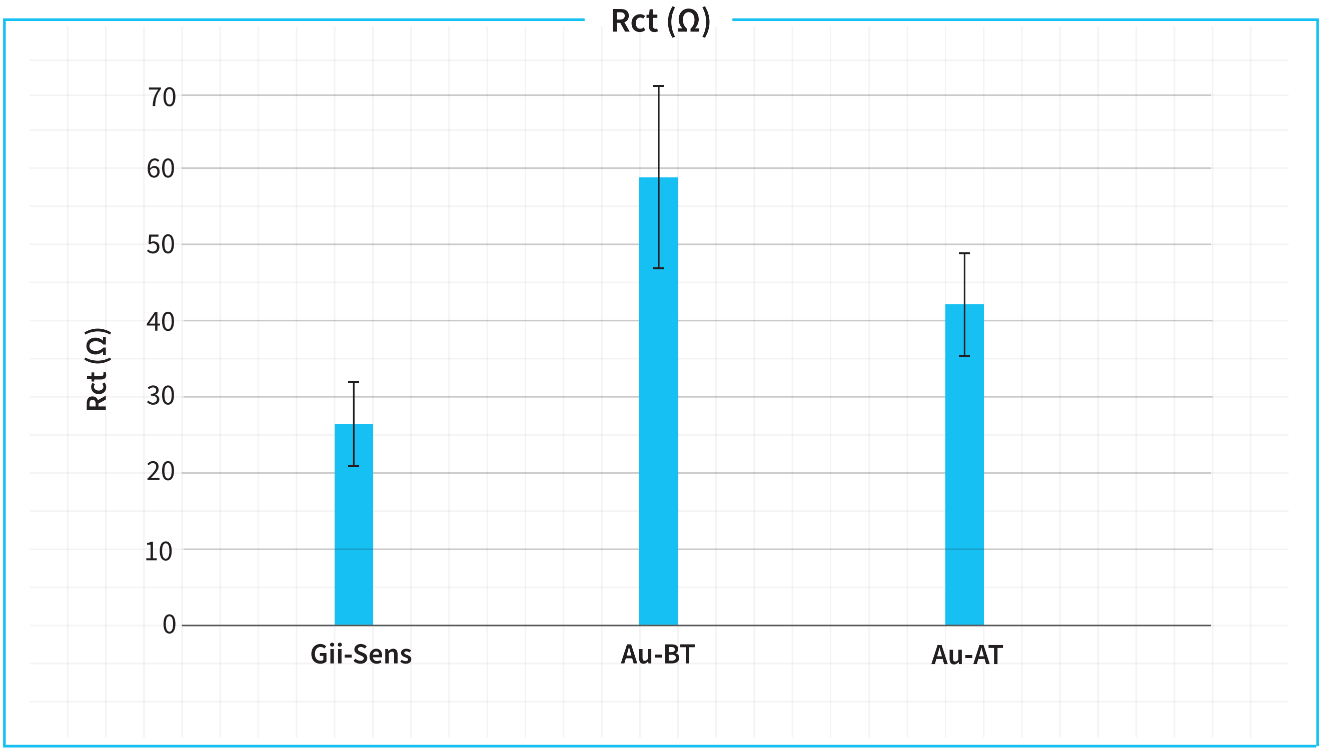


Figure 9: Charge transfer resistance (Rct Ω), calculated by EIS, of Gii-Sens, Au-BT and Au-AT screen-printed gold electrodes. Gii-Sens shows lower resistivity than the two screen-printed gold electrodes.

## Conclusions

The performance of Gii-Sens sensors outplays any other carbon-based or even graphene-based sensor available on the market. Even screen-printed gold surfaces are outperformed, which positions Gii-Sens as the ultimate transducing element. Gii-Sens reveals for the first time the perfect choice for scalable manufacturing for electroanalytical applications while maintaining a top performance, ensuring maximum sensitivity and flexibility for implementing into large throughput and point-of-care applications.

We hope you have found the data in this analysis compelling with regards to the efficacy of the performance of Gii when compared with other, incumbent sensing materials. Gii-Sens has already proven to be a step-change in how patients and clinicians access results at the point of need. Integrated Graphene are committed to working with as many researchers as possible to enable better healthcare through this technology. To support this activity, we have a full spectrum of chemistry development and microfluidic services.

The benefits of graphene can therefore revolutionise all aspects of diagnostics.

If you would like to test Gii-Sens, then it is available to purchase now from the Integrated Graphene shop. For more information on the performance data referenced in this document, or to speak with one of our principal scientists, please contact us today to discuss your requirements.

For more information about the products we offer, please visit:
www.**integratedgraphene**.com

**Interested to learn more?**

Why not book a meeting with our commercial and/or scientific leads:

Alastair Carrington
Chief Commercial Officer

Pablo Lozano Sanchez
Principal Scientist

**Book Meeting**

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