Gii-Sens
Electrode Performance Comparison

An introductory comparison of premium commercially available electrode performance.

SCAN FOR MORE INFO

This report investigates the comparison of the Gii-Sens electrode to other electrodes on the market.

If you are interested in testing Gii-Sens or looking at the other products by Integrated Graphene, please follow the QR code to the left.

Contents

Integrated Graphene: An Overview

Who We Are

Our journey started with a question. How can we make a scalable product and process at minimal cost, suitable for easy integration? To answer this our founders worked to develop a patented, 'design for manufacture' process to grow high-performing, low-cost, pure 3D Graphene (3DG) – called Gii®. Since then, our company has worked with some of the leading blue-chip bioassay manufacturers to streamline their process and enhance profitability. But how?

Set to disrupt the industry, Gii-Sens provides manufacturers and R&D teams the opportunity to achieve the performance of precious metal electrodes but at the cost of screen printed carbon.

This improvement in sensitivity, reliability, and conductivity can be attributed to not only our unique manufacturing process but the unique 3D structure of the material. Gii-Sens facilitates accurate, multiplexed point-of-care diagnostic testing in a much shorter timeframe than conventional laboratory testing, due to its large electrochemically active area.

Gii-Sens Summary

An assessment of our electrodes against commercially available alternatives clearly shows that Gii-Sens successfully outperforms, or equals, all of these traditional sensing electrode materials on key performance metrics e.g. reduction-oxidation peak current density, reduction-oxidation peak separation and surface charge transfer resistance. Gii-Sens will advance the transition away from finite noble metals to a more stable, sustainable graphene market without compromising on performance.

Gii-Sens offers clients improved performance, seamless manufacturing integration all with a lower cost.

Integrated Graphene not only offers the Gii-Sens platform but a range of individually tailored solutions to develop the future of novel, powerful, and cost-effective microfluidic assays. Plus, device development services from concept to high volume manufacturing.

Data Summary Table

Electrode	Reduction - Oxidation Peak Current Density (µA/cm²)		ΔEp (Reduction - Oxidation): Average ΔEp (mV)			Surface Charge Resistance: Average Rct (Ω)
	+Max -Min	Ratio Max : Min	25 mV/s	200 mV/s	Difference	
Gii-Sens	+198.1 -198.1	1 : 1	68.29	67.63	-0.67	26.34
Company D Graphene	+161.7 -178.2	1 : 1.10	83.36	123.83	40.47	600.00
Company Z Graphene	+158.6 -143.4	1 : 0.90	166.22	287.11	120.89	3953.00
Company D Graphite	+130.47 -135.24	1 : 1.04	128.55	221.48	92.93	412.01
Company Z Glassy Carbon	+194.29 -195.71	1 : 1.01	70.90	86.11	15.21	212.23
Au-BT	+164.28 -179.79	1 : 1.09	69.00	75.71	6.71	58.18
Au-At	+162.29 -179.79	1 : 1.11	67.12	70.21	3.09	42.00

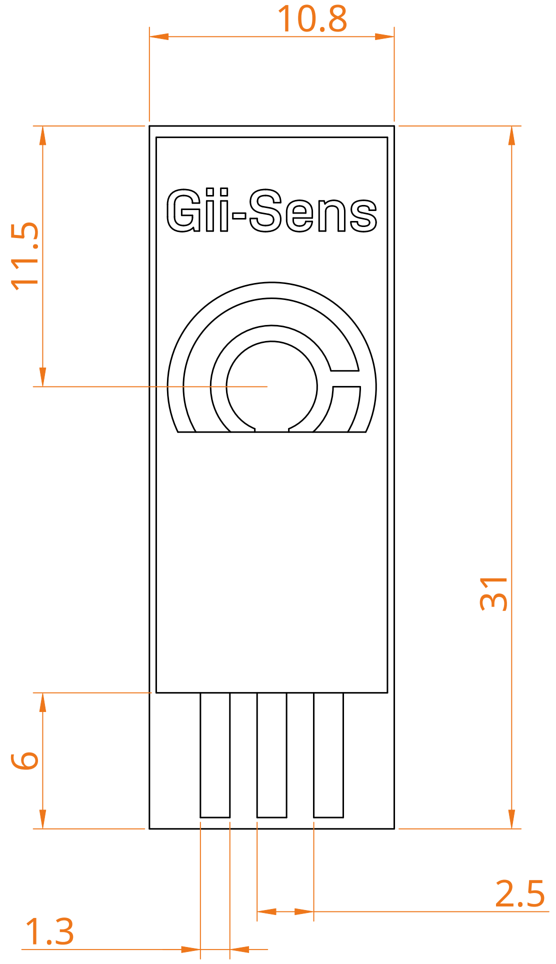
Technical Background

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.

READ DATASHEET

Gii-Sens Technical Drawing



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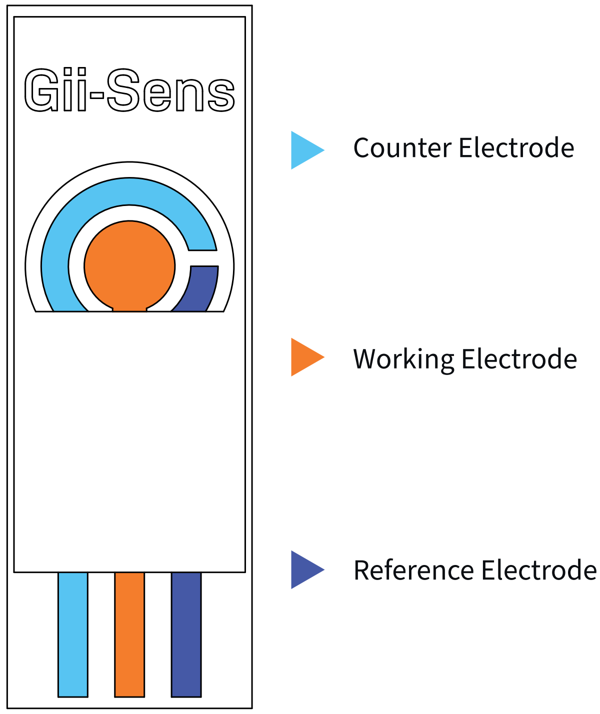

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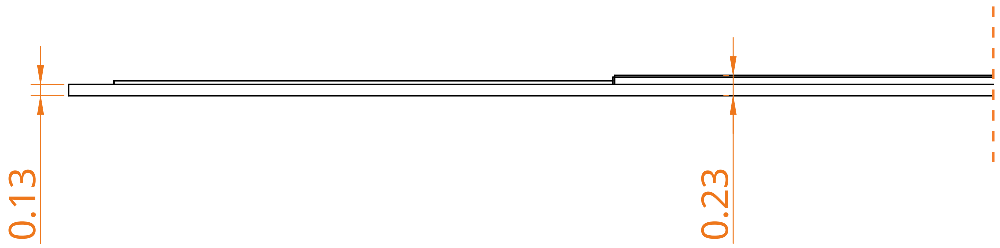

SIDE (PART-VIEW)
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Gii-Sens vs. Other Graphene Electrode Materials

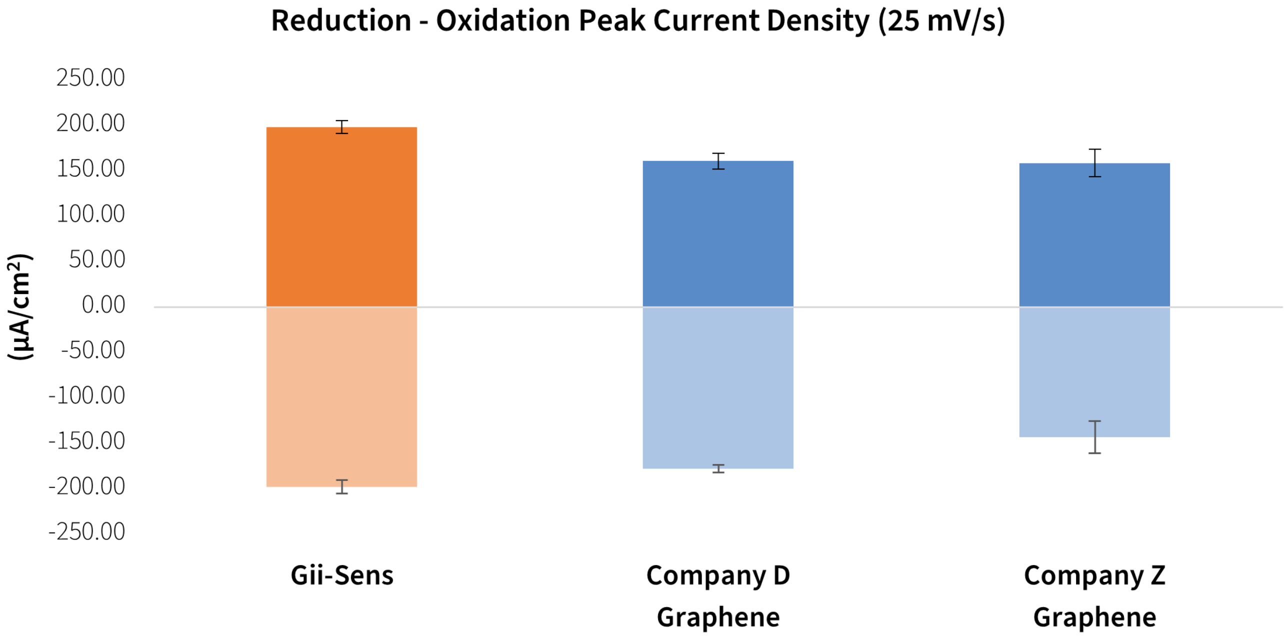
Gii-Sens was evaluated and compared against two premium commercially available graphene based sensors: Company D graphene and Company Z graphene.

The results show that Gii-Sens had an increased electrochemically active area by 25%. Thus, offering a much lower reduction – oxidation peak separation below 70 mV with no sign of increased separation from 25 to 200 mV/s. Clearly, Gii's larger electrochemically active surface area results in better discrimination. Thus, overcoming the reproducibility and scalability issues of current graphene-based electrodes on the market.

SUMMARY
Gii-Sens increased the electrochemically active area by 25% resulting in superior discrimination. Ultimately, creating reproducible results available at scale.

Reduction Oxidation Peak Current Density

Cyclic voltammetry allows an assessment of the relative electrochemically active surface area of each material by measuring the reduction – oxidation peak current density. 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 with both commonly used alternatives.

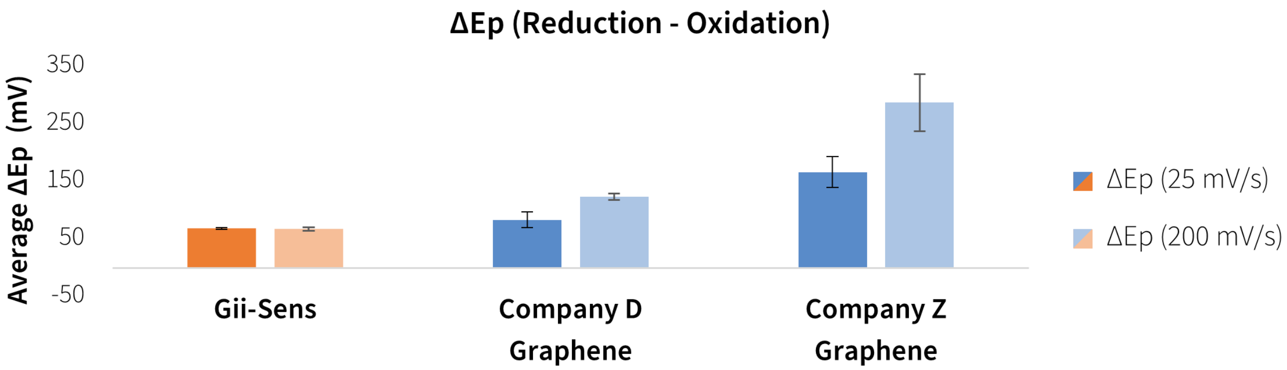


Electrode	Gii-Sens	Company D Graphene	Company Z Graphene
Ratio (Max : Min)	1 : 1	1 : 1.10	1 : 0.90

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 Current Density

Furthermore, 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. These show the superior responsiveness of Gii-Sens which can be attributed to better signal discrimination and increased potential to achieve higher accuracy.



Electrode	Gii-Sens	Company D Graphene	Company Z Graphene
Difference between 25 and 200 mV/s	-0.67	40.47	120.89

Figure 2: Reduction – oxidation peak separation (ΔEp) at 25 mV and 200 mV 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 25 mV/s and 200 mV/s.

Surface Charge Transfer Resistance

To measure charge transfer resistance (Rct Ω), electrochemical impedance spectroscopy (EIS) was performed 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.

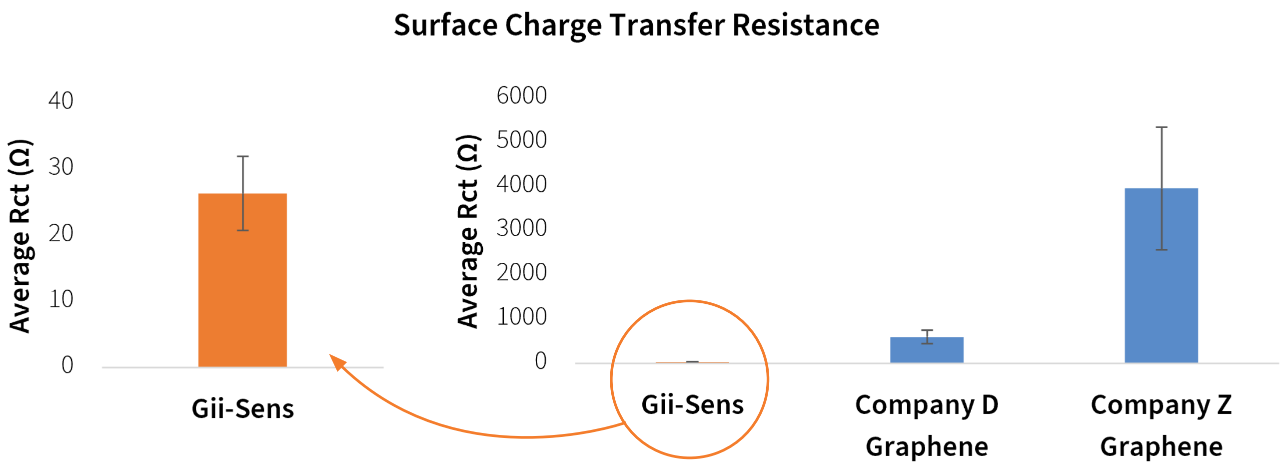


Figure 3: Charge transfer resistance (Rct Ω) of Gii-Sens measured by EIS, Company D Graphene and Company Z Graphene. Gii-Sens has much lower charge transfer resistance at the sensor surface when compared to Company D Graphene and Company Z Graphene.

Gii-Sens vs. Other Premium Carbon-Based Materials

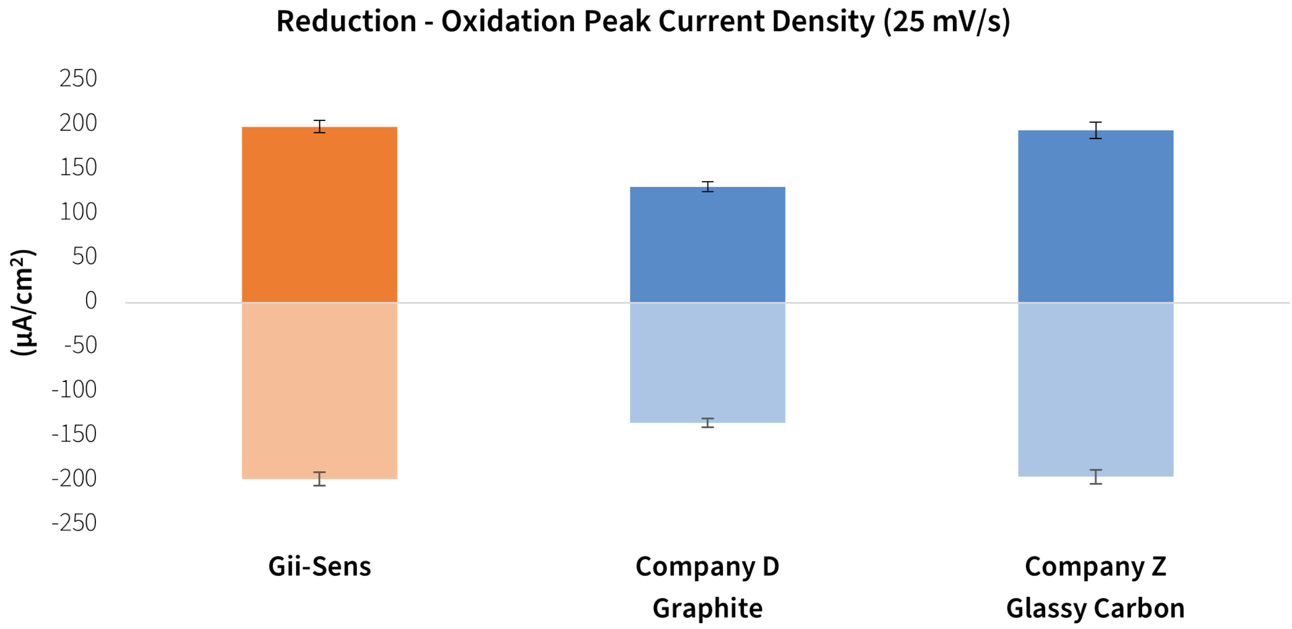
Carbon-based electrodes are common throughout electroanalytical applications with carbon paste standard material for screen-printed sensors. Typically, these are the most widely used electrode surfaces in real point-of-care applications due to their fabrication flexibility and affordability.

Currently, glassy carbon electrodes promises optimum performance. However, this option is restricted in terms of flexibility of manufacturing and broader affordability. Gii-Sens not only outperforms such carbon-based electrodes but fills the gap in the market for an electrode which can scale at very low costs without impacting on performance.

SUMMARY
Gii-Sens outperforms other premium carbon based electrodes as well as providing a solution for low-cost scale-up without compromising on performance.

Reduction Oxidation Peak Current Density

To highlight this difference in performance, we measured reduction – oxidation current density by cyclic voltammetry to allow for a comparison of pure glassy carbon versus Gii-Sens. This demonstrates that Gii-Sens not only matches the performance of pure glassy carbon in terms of available electrochemically active area but increases the area available at equivalent sized carbon paste electrodes by 50% (Figure 4).

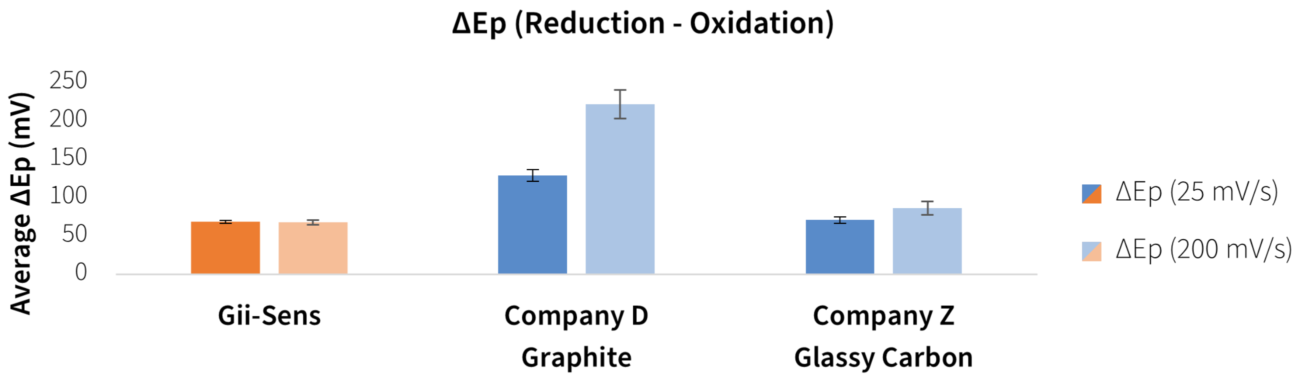


Electrode	Gii-Sens	Company D Graphite	Company Z Glassy Carbon
Ratio (Max : Min)	1 : 1	1 : 1.04	1 : 1.01

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 Current Density

Allowing for a comparison between our graphene material against carbon paste we measured the reduction – oxidation peak separation obtained from cyclic voltammetry (Figure 5). This figure 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 outperforms that of pure glassy carbon at any chosen scan rate, showing its great potential in combining manufacturing flexibility and outstanding performance.



Electrode	Gii-Sens	Company D Graphite	Company Z Glassy Carbon
Difference between 25 and 200 mV/s	-0.67	92.93	15.21

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

Surface 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 emphasize 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.

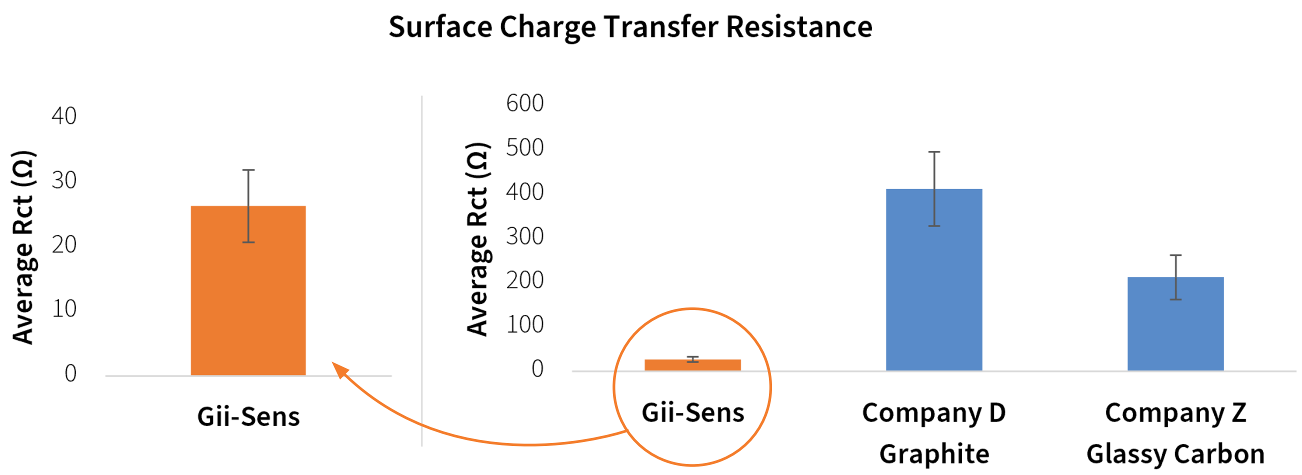


Figure 6: Charge transfer resistance (Rct Ω) of Gii-Sens, Company D Graphite and a glassy carbon electrode. Gii-Sens shows a much lower Rct than the other two electrodes tested.

Gii-Sens vs. Screen-Printed Gold

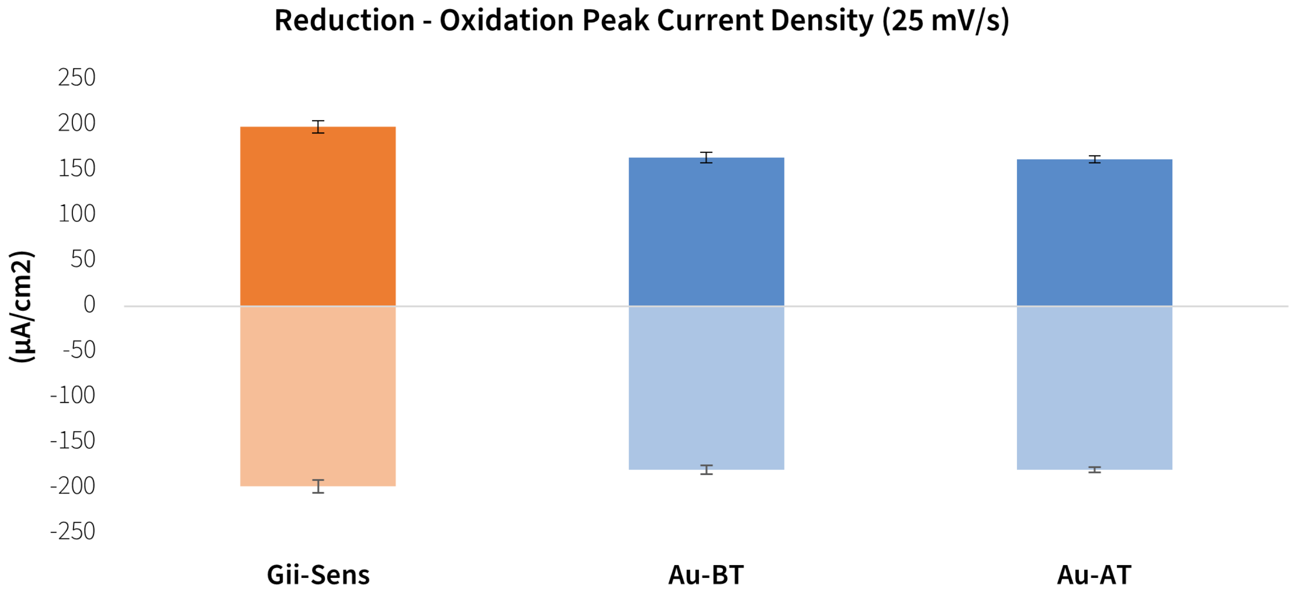
The most important properties required to make a sensor material feasible for existing electrochemistry sensing applications include excellent electrochemical responsiveness and flexible fabrication procedures, requiring little infrastructure for production. Screen-printed gold sensors have been widely selected due to these characteristics. However, Gii-Sens graphene provides these benefits but with the additional benefit of added performance, affordability and sustainability.

To demonstrate this, two commercially available examples of screen-printed gold were evaluated against Gii-Sens. Gii-Sens not only matched the performance of the screen-printed gold electrodes but utilises a more sustainable production process. This will enable the diagnostic industry to access the performance of gold at low costs and potentially improve performance.

SUMMARY
Gii-Sens not only matched the performance of the screen-printed gold but included the benefits of lower cost price and enhanced scalability.

Reduction Oxidation Peak Current Density

In order to measure reduction – oxidation current density as an indicator of electrochemical potential 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.



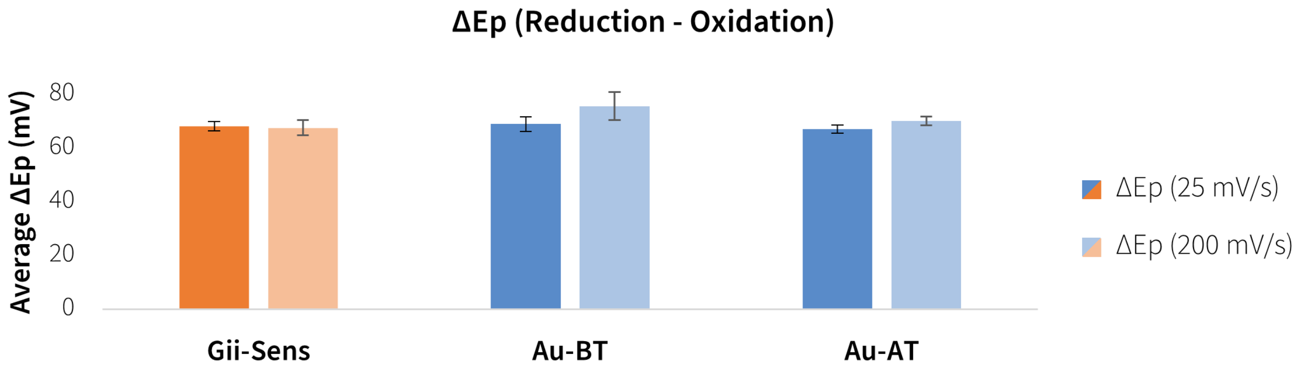
Electrode	Gii-Sens	Au-BT	Au-AT
Ratio (Max : Min)	1 : 1	1 : 1.09	1 : 1.11

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.

Reduction Oxidation Peak Current Density

In order to measure reduction – oxidation current density as an indicator of electrochemical potential 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.

Not only this, electrode surface responsiveness can be matched or even in some instances improved. 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.



Electrode	Gii-Sens	Au-BT	Au-AT
Difference between 25 and 200 mV/s	-0.67	6.71	3.09

Figure 8: Cyclic voltammetry reduction – oxidation peak separation (ΔEp) at 25 mV and 200 mV 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.

Surface 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. When you compare Gii-Sens and screen-printed gold using these metrics it's clear that Gii-Sens offers a winning combination of ease of manufacturing and outstanding performance. Crucially, with the scalability potential to generate substantial financial savings.

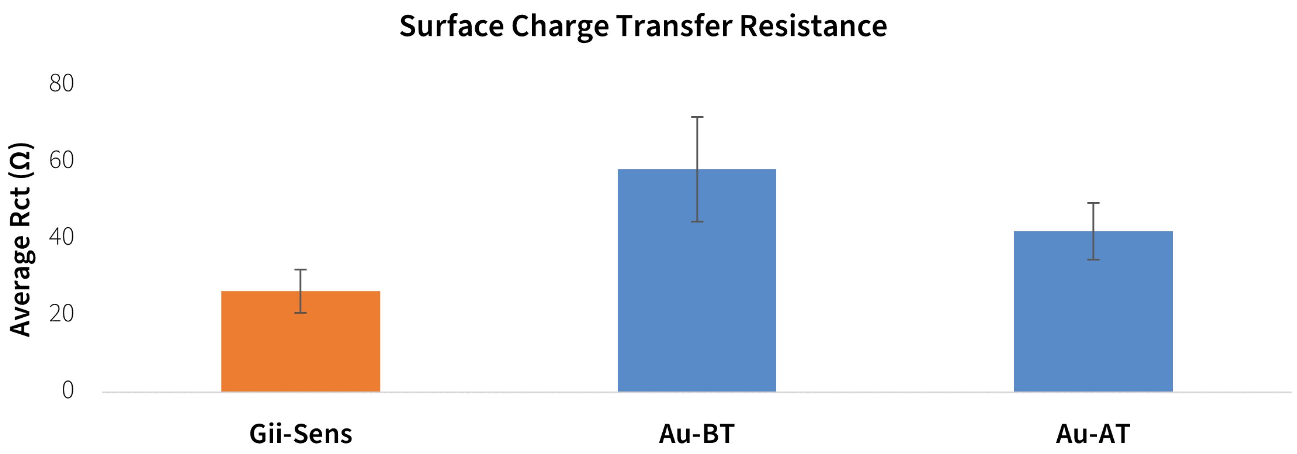


Figure 9: Charge transfer resistance (Rct Ω), calculated by EIS, of Gii-Sens, Au-BT and Au-AT screen-printed gold electrodes. Gii-Sens shows lower resistivity than the two screen-printed gold electrodes.

Conclusions

Gii-Sens sensors outperform any other carbon or graphene-based sensor available on the market, including screen-printed gold surfaces.

This is what positions Gii-Sens as the ultimate transducing element. Gii-Sens offers, for the first time, the perfect combination of scalable manufacturing for electroanalytical applications while maintaining top performance. Ensuring maximum sensitivity and flexibility for implementation into large throughput and point-of care applications will open up new avenues of application with real world impacts on the diagnostic sector and beyond. The scope of this innovation can be applied to many sectors including but not limited to animal and environmental testing.

Closing Remarks

Our data provides compelling evidence with regards to the efficacy of the performance of Gii when compared with other, incumbent sensing materials. Integrated Graphene are committed to working with as many stakeholders as possible with the ambition of making our technology available to the masses and ultimately, enabling better healthcare at the point of need. We offer a comprehensive suite of products and services from assay development through to high volume manufacturing which places us in a unique market position. Gii-Sens has already proven to be a step-change in how patients and clinicians access results to inform health care decision making. The benefits of graphene clearly offer the potential to revolutionize all aspects of diagnostics and disrupt the industry for the better.

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Interested in Learning More?

Contact us today to discuss your requirements via email at: info@integratedgraphene.com

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

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